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THE BRITISH JOURNAL OF METALS

Vol. 48 No. 286 AUGUST, 1953 27 AUG 1953 Monthly: TWO SHILLINGS

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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

AUGUST, 1953 Vol. XLVIII. No. 286

Science and Industry

IT has been suggested that our economic difficulties are the result of "technical backwardness" in British industry, and whilst we cannot accept the suggestion as it stands, in that our problems are, in the first place, an aftermath of the war, it must be admitted that our failure to exploit the results of scientific research is one—but not by any means the only one—of the factors delaying our economic recovery. It would, however, not be exaggerating the importance of the matter to say that this factor is one of paramount importance and the Sixth Annual Report of the Advisory Council on Scientific Policy (1952–1953)* is devoted entirely to a discussion of the effectiveness of current arrangements for ensuring that the results of research make their contribution to the development of the British economy at the present time—a question referred to it last year by the then Lord President of the Council, Lord Woolton.

It is mainly in comparison with its American counterpart that charges of conservatism are levelled at British industry, but there are grounds for belief that some sections, at least, of European industry are more go ahead. However, the facts concerning American industry are more readily available and some interesting conclusions can be drawn from them. Although there are a number of firms in this country—mostly among the larger ones—which are as efficient in their application of scientific research as any in the world, there are still many large firms which appear content to carry on with the minimum of technical change. It is in the medium-sized and smaller firms, however, that inefficiency in this respect is most widespread, and almost a quarter of the labour force in British industry is in firms employing 50 men or less, as compared with a sixth in the United States.

One vital factor bearing on the present state of affairs is, undoubtedly, the comparative shortage of technically qualified people in many parts of British industry. There must be an increase in the numbers of scientists and engineers employed in industry, and an improvement in their average quality, if we are not to continue to lag behind. This problem of improving the scientific manpower position has been under active consideration in recent years, and steps towards a solution have already been taken. It is one thing to increase the supply of scientists and engineers, however, and quite another matter to get them accepted by industry as a solution to its problems. The Report suggests that the primary reason why British industry as a whole does not make more use of scientists is not because their numbers were, and are, insufficient, but because large sections of industry, being conservative and complacent, have neither missed them nor asked for them. Had the demand been there, it would surely have been matched by a supply of adequately trained men.

* H.M. Stationery Office: Price 6d.

It is not only in the laboratories and workshops that scientists and engineers are required, however: they are also urgently needed in the board rooms, if full and speedy advantage is to be taken of the remarkable scientific advances of the present day. It is no mere coincidence that the enormous growth of American production has taken place at the same time as an increasing representation in management of men with a strong scientific or technical background. Britain was once the main supplier of manufactured goods to other, less highly developed countries, but to-day, we can hardly expect to live by our industry unless we seek to develop new products and processes, which, by depending on the application of our scientific knowledge and engineering skills—which are as good as can be found in any country—will keep us in the forefront.

Although the development of new products and processes depends on scientific research and its application, its scale is governed by the level of investment in manufacturing industry and by the willingness of manufacturers to use available funds for this purpose. The level of investment is low compared with the United States, and this results in a serious shortage of risk capital to finance large innovations. It is probable, therefore, that many of the brighter and more speculative ideas find no financial support at all, and are thereby lost to the nation. The most effective single measure which would conduce to a greater exploitation of science by industry would be a significant increase in the volume of investment, but major improvements cannot be expected until big changes in Government policy become possible.

On considering the means of narrowing the gap between scientific discovery and industrial output, assuming no major change in the existing level of investment, the Council has concluded that control by licensing of industrial building now has a negligible effect, and that the inducements to research and development already provided by our taxation system leave little scope for further relief.

The smaller firms do not usually employ scientists and they are also limited, by their lack of capital, in the use they can make of the work of Research Associations. Very few of them could bear the cost of developing an idea through the pilot-plant stage to full-scale production, nor could they find the resources to have it done on a contract basis. It is by improved productivity that the output of medium and small firms can be most economically increased, and D.S.I.R.'s policy of developing the work of the Research Associations in this field should prove invaluable.

Industrial firms producing equipment for defence are generally assisted by means of research and development contracts and the Council has considered whether such contracts could be used to stimulate developments in private manufacturing industry, where the Government is not a consumer of the products. Whilst civil

Departments might find it valuable to place development contracts in connection with long-term needs, which the country cannot afford to ignore, but which have no immediate financial attraction for industry; developments in private industry normally derive from initiative within the industry itself. The Research Associations are, therefore, more favourably placed than Government Departments or the National Research Development Corporation to foster desirable development projects, possibly by bringing into being Development Companies, run on a commercial basis by the industries themselves in conjunction with their Research Associations. If public money is to be spent on civil industrial development, financial assistance in launching such companies, so that they in turn could revitalise old industries, might be a sounder investment than money spent on development contracts initiated from outside the industry concerned.

Commonwealth Bursaries Scheme

The Royal Society and the Nuffield Foundation, in order to fill a need with respect to Commonwealth scientific relations, have jointly decided to initiate a Commonwealth Bursaries scheme. The Nuffield Foundadation is supporting this bursary scheme as a complement to its established programme of Commonwealth Fellowships and other awards.

Put concisely, the objective of the scheme is to provide facilities for increasing the efficiency of investigators of proven worth by enabling them to pursue research, learn techniques or follow other forms of study where either or both the physical and personal environment overseas in the Commonwealth is peculiarly favourable. The main difference from the ordinary research fellowship is not merely one of duration, but of emphasis, as the bursaries will aim not so much at obtaining the answer to a particular question as at improving the powers of the recipient to extend the bounds of knowledge.

The scheme will be operated for an experimental period of five years, during which time the Nuffield Foundation will provide £5,000 a year and this will be devoted to bursaries to United Kingdom scientists who wish to go to overseas parts of the Commonwealth and to scientists of one oversea part of the Commonwealth to go to another. Initially, the Royal Society will also make a contribution of £2,500 which will be available for movement in any direction within the Commonwealth including to the United Kingdom. It is, however, hoped that funds may be obtained from other sources, particularly from overseas, to make possible the full development of the scheme, especially by increasing the proportion of bursaries available for scientists of oversea countries of the Commonwealth who desire facilities in the United Kingdom.

Each bursary will provide for the cost of travel and maintenance, normally for periods of two to twelve months. It will not aim at the provision of any salary, as such, but of sufficient maintenance to avoid frustration. The applicant must be sponsored by a recognised research authority and must produce evidence that he or she has prior permission to work in the laboratory or other scientific institution chosen. It is expected that in the operation of the scheme Fellows of the Royal Society throughout the Commonwealth will assist in sponsoring and assessing applicants for bursaries.

A joint Royal Society and Nuffield Foundation Commonwealth Bursaries Committee has been set up to administer the scheme on behalf of the sponsors. Its membership is as follows :—

Chairman : Sir Edward Salisbury, C.B.E., Sec.R.S.
Nominated by Trustees of the Nuffield Foundation : Mr. Leslie Farrer-Brown, Sir John Stopford, F.R.S., and Professor A. R. Todd, F.R.S.
Nominated by Council of the Royal Society : Professor G. R. Cameron, F.R.S., Professor H. S. W. Massey, F.R.S., and Sir Eric Rideal, F.R.S.
with Dr. D. C. Martin, Assistant Secretary, Royal Society, as Secretary to the joint committee.

It is proposed initially to consider applications at six-monthly intervals, beginning early in 1954. Application forms containing further details will be obtainable from the Assistant Secretary, The Royal Society, Burlington House, Piccadilly, London, W.1., and must be submitted not later than 15th March and 15th September in each year.

International Engineering Congress

The 5th International Mechanical Engineering Congress will be held in Turin from October 9th to 15th, 1953, at the Palazzo delle Esposizioni del Valentino, within the scope of the Salone Internazionale della Tecnica, which will be visited by participants. The A.M.M.A. (Associazione Metallurgici Meccanici Affini) has undertaken, on behalf of the Organising Committee, the arrangements for this 5th Congress.

The theme will be "Production and Assembly Methods for Components in Mechanical Engineering"; that is to say, the Congress will examine and compare, from the technical and economic viewpoints, the various methods available to manufacturers. In view of the wide range of the theme chosen, questions of raw materials, measurement, inspection and methods of erection will not be considered.

Arrangements have been made for factory visits, during the week of the Congress, to certain industrial undertakings, amongst which are : various factories of the Fiat Group (motor cars, lorries, tractors, aeroplanes, marine engines, machine tools, steel works and foundries) ; Cogne (iron and steel production and metallurgy) ; Microtecnica (engineering and precision instruments, gyroscopic compasses, cinematograph apparatus) ; Olivetti (calculating machines and typewriters, machine tools) ; Riv (bearings, cash registers, plastics).

A study tour by motor coach will be made during the week immediately following the Congress. Two alternative itineraries are available, each in the first stage covering the same journey, which will afford opportunity not only for visiting important industrial undertakings in the north and centre of Italy, but also for appreciating some of the more beautiful parts of Italy at a particularly agreeable season of the year.

The British Engineers' Association, 32, Victoria Street, London, S.W.1, represents the United Kingdom interests on the Organising Committee of the Congress.

Change of Telephone Numbers

British Insulated Callender's Cables, Ltd., announce that the new telephone number of their Derby Depot is Derby 43697. The telephone number of their Southampton Branch Office has also been changed, to Southampton 76176/7.

Carbon in the Engineering and Metallurgical Industries

I—Historical Introduction and Constitution of Carbon Allotropes

By V. S. Kingswood, M.Sc., B.Sc., F.I.M.

Deputy Head of the Metallurgy Department, Battersea Polytechnic

The properties of carbon in its various allotropic forms are such that it finds application in a wide range of products, from rubber tyres to blast-furnace linings, and from mould dressings to rock drills. In this first article of the series, the author presents a historical survey of the industrial use of carbon before proceeding to a discussion of the constitution of the various forms of carbon. Further articles will deal in some detail with the practical applications of this material.

CARBON in its elemental or allotropic and manufactured forms, apart from its use as a fuel, plays a very important part to-day in the engineering industries.

From the pre-Christian era we find the diamond in use as a gem, but its value as a cutting agent has also been known in the East for about 1,000 years, whilst natural graphite from the time of the Middle Ages has found application as a writing or drawing medium, and as an ingredient used in the manufacture of crucibles for melting brass- and bronze-type alloys.

Carbon as charcoal, bone black and, later, lampblack has for some four hundred years found application as a pigment, and has been used widely in printers' inks. Now such widely diverse applications as carbon papers and ribbons for typewriting, gramophone records, tyres and other hard-wearing rubber products, paints, lacquers and varnishes, decolourising media for sugar refining, and gas adsorbing materials, all require carbon in one of its many forms.

From its small significance in early times, the element has now assumed very important roles, and both industrial and social life as it is in the 20th century would be impossible without it. To understand more clearly this sweeping statement we need but mention a few applications covering an extremely wide field of usage.

Diamonds are used for industrial drills, dies and cutters for the exploitation of mineral and coal seams, and in dies for the production of fine wires. Natural graphite is a major constituent in the manufacture of melting crucibles, certain moulds, mould dressings and facing sands, and ancillary equipment in the steel industry (ladle stoppers and nozzles, heat-treatment boxes, etc.); in lubricating mixtures for use at high temperature or in chemical or other plants; in the rubber tyre industry for hardening and improving wear resistance; and in pencil and electrical brush manufacture.

Artificial graphite, whose properties can be adjusted during manufacture, is a more flexible material and finds wide industrial use: in the carbide industries for furnace parts and moulds; in chemical engineering as a material of construction in very many applications; as the main constituent in arc-furnace electrodes in steel melting and other high-temperature processes; in moulds for the glass and electronic tube industries; and in atomic energy piles as a "moderator" for controlling neutron speeds.

Finally, carbon in its many forms may be found as electrodes in the welding, dry battery, arc lighting and arc furnace industries; as a carburising agent in heat-treatment processes for steels; in electrical brushes, resistors and refractories; in telephone construction, and as electronic tube anodes; and in the engineering and other industries.

It will be appreciated from the enormous scope of this subject that some generalisation must be made for the minor applications where these fall outside the field of engineering. For the rest, in the remainder of this series of articles, the field of engineering applications of carbon will be discussed under appropriate headings.

Historical Review[1]

Apart from the first applications of clay-graphite mixtures for crucible making in Elizabethen times, it was only some 150 years ago that Sir Humphrey Davy made the first real step towards applying carbon to an industrial need. In experiments at the Royal Institution on the electric arc, he fabricated electrodes of charcoal cut from lengths of carbonised wood. These were rapidly consumed, and he improved them in this respect by moulding powdered wood charcoal bonded with tar under a pressure of 100 lb./sq. in., followed by careful baking. These electrodes gave a satisfactory 4-in. arc and this was the beginning of arc-furnace development. During the next 50 years, various mixtures were patented for electrode manufacture, many of which incorporated sugar as a bond, and some used pulverised coke instead of wood charcoal. Foucault, about 1840, was the first to use gas retort carbon (from gas works retorts). All used moulding under pressure followed by baking. The next ten years saw many abortive experiments carried out with a view to purifying the electrodes, principally from the point of view of silica removal. To this end, immersion in fused caustic salts and treatment in gaseous chlorine were tried.

By the late 19th century, many mixtures incorporating lampblack, resins, pitches, tars, coals, oils, as well as the aforementioned charcoal, coke and sugar, were tested for the purpose of developing carbon electrodes for the recently developed arc lighting industry.

Carre[2] is considered to be the man who developed this field, and his method of extruding a warm paste made up of finely ground coke and lampblack with sugar syrup as a binder is still largely followed to-day. Baking to high temperature out of contact with air followed the extrusion process.

About the same time, Fowler in the U.S.A. started moulding battery plates, and in the same country Brush, using calcined petroleum coke mixtures moulded hydraulically under great pressures, made electrodes which, after baking in a protective atmosphere at high temperature, were used in 1886 by Hall in the experiments which led to aluminium extraction from bauxite by electrolytic reduction.

Within the next five years, Siemens, Cowles and Heroult developed furnaces using the carbon arc or a carbon resistor rod as a source of heat. The development of the aluminium producing industry, pioneered by Hall and Heroult separately, soon brought a demand for large electrodes for use in the reduction furnace, and also for use in the Heroult-type arc furnace. In the last decade of the 19th century, Acheson, working on abrasives, developed " carborundum " or silicon carbide, and during these high-temperature experiments in a carbon resistor furnace he discovered that carbon could be converted artificially into graphite. This led to the development of the very important Acheson electrographitising process[3] for the manufacture of graphitic electrodes and other articles with controllable physical and mechanical properties. Acheson material was soon being used by Castner for his alkali plant producing sodium and caustic soda.

The National Carbon Company in the U.S.A. started manufacture of carbon brushes in 1886 from a British patent of the previous year, and in 1888, Gassner, using carbon rod electrodes, converted Leclanche's wet cell to the modern dry counterpart, and laid the foundations for the present dry battery industry. Heroult's arc furnace in 1895–7 was soon adapted to the making of steel and the ferro-alloys ferrosilicon and ferro-chrome, whilst electrolytic chlorine produced from sodium chloride soon resulted from the use of graphite electrode electrolytic cells.

At the turn of the century, work in France by Heroult and Hardmuth, and in Germany by Plania and Siemens, proceeded with the aim of producing carbon and graphite electrodes for furnace work using cheaper and more easily obtainable anthracite as the main raw material.

About the same time, various workers in Europe and America were introducing metallic salts into arc light carbon electrodes to produce more light by means of a flaming arc—this was then applied to street lights and searchlights. In this respect, lampblack gradually superseded petroleum coke in their manufacture. Of course, arc lighting was very soon replaced by the more satisfactory tungsten filament lamps for many purposes.

Furnace Electrodes

The production of large furnace electrodes developed slowly, but was encouraged by the demand by the ferro-alloy industry which was developing in Europe alongside the aluminium industry. The reason for their association appears to be the common requirement for cheap power, usually from hydro-electric sources. By 1906, electrodes up to 8 in. diameter by 48 in. long were being produced, and were provided with threaded ends or sockets for joining further lengths—an ingenious idea for furnace work which is still common practice.

The German carbon industry was also flourishing and was manufacturing round and square electrodes of large size by moulding at high pressures, and in most cases using electrically calcined anthracite coals for the main raw material.

The 1914–18 war brought about rapid expansion in the electric furnace and electro-chemical industries, and with it a demand for bigger and more varied shapes of electrodes. Up to 24 in. diameter in carbon and up to 8 in. diameter in electrographite were now being produced. By 1928 these sizes had increased to 40 in. diameter and 16 in. diameter, respectively.

Parallel to the historical development of electrodes, we find carbon bricks and carbon paste made from ground coke and tar used for the hearth linings of blast furnaces making iron and ferro-alloys in Germany as long ago as 1866. About 1900 this principle was applied to calcium carbide and phosphorus extraction furnaces.

With the introduction of the carbide industry to this country about 30 years ago, the use of carbon and graphite for furnace tubes, boats and later moulds for casting and hot pressing has become progressively more important.

The corrosion resistant properties of carbon and graphite have been known for about one hundred years, but only in the last twenty years have we seen these materials used for the construction of chemical engineering plant, in which field a wide range of products now find an ever increasing application.

From 1930 to the present day both carbon and graphite have been used successfully in most of the engineering industries. In brief, we have brushes, resistors, current collectors and thermionic anodes in the electrical engineering field; heat exchangers, scrubbing towers, filters, Cottrell plant pipes, pumps, tank linings, ductings and reaction-vessel linings, to quote a few applications in the chemical engineering field; and in the metallurgical field: applications in the foundry as moulds, mould plugs, mould facings, riser rods; in the iron and steel industry with furnace linings, iron troughs, electrodes; in the carbide industry, heat-treatment crucibles and muffles and many other applications. In the field of mechanical engineering, oil-less bearings, dash pot plungers, clutch facings and rings, and pump sealing rings, etc., are now well established.

THE CONSTITUTION OF CARBON AND GRAPHITE

Although diamonds and graphite have both been known to man for over 2,000 years, it was not until the late 18th century that Scheele showed both to be of similar origin by the combustion of natural graphite in oxygen and measurement of the volume of carbon-dioxide produced. This showed agreement with similar experiments on natural diamonds by D'Arcet, Tennant and others (1772–97). The name graphite is attributed to the mineralogist Werner (1789).

Amorphous carbons as we know them to-day are all manufactured products, but some natural graphites may be termed " amorphous " or microcrystalline. We shall see later, however, that all the natural forms of carbon—diamond, crystalline graphite and " amorphous " graphite—are crystalline.

Since the 17th century much confusion has existed as a result of minerals such as molybdenite—which is soft, grey, and marks paper—being classified as graphites,

and in a similar manner diamond could be confused with various hard minerals and, later, with extremely hard electric furnace products of the carbide and boride variety.

Graphitic Oxide

Experiments by Brodie,[4] using oxidising mixtures of nitric acid with potassium chlorate on various forms of carbon, showed that only those which gave a yellow solid (he called it graphitic acid or oxide and gave the formula $C_{11}H_4O_6$) could be classified as "graphite": carbons gave a mixture of humic and mellitic acids with carbon monoxide or dioxide evolved.

This work was extended by Berthelot in his classical researches (about 1870) on the properties of carbon and graphite. He showed, using Brodie's technique, that the colour of "graphitic" oxide could vary from green to brown, depending on the duration of oxidation treatment, but by controlling the reaction at 60° C. for 12 hours he obtained a consistent product in the form of greasy pale yellow crystals.

Luzi,[5] in 1891, showed that with natural graphites classified by Brodie's test, some (Ceylon and American varieties) swelled on treatment with concentrated nitric acid, whilst others (Austrian and Cumberland varieties—also graphite from grey cast irons) did not. To differentiate them, he called the first group "graphites" and the others "graphitites."

Further work by Berthelot showed that graphitic oxide from some natural graphites (and also from some artificial graphites produced under pressure) decomposed on heating by swelling (called "intumescence"), and finally gave a finely divided carbon to which the name pyrographitic acid or oxide was given. Swelling starts about 170° C. and is thought to be due to the rapid evolution of gases (resulting from the possible presence of oxygen atoms, hydroxyl groups or water molecules from the initial acid treatment) intercalated between the layer planes of the graphite. More recent ideas on the nature of pyrographitic oxide suggest that it is finely divided graphite containing a small amount of residual oxygen.

Many physical tests on a variety of carbonaceous materials showed Berthelot that the true graphites, although giving slightly variable results, had a specific gravity between 2·1 and 2·3, a high carbon percentage, negligible ash, and a combustion temperature in oxygen of about 660° C. (Natural graphites of course had varying proportions of mineral matter present, which gave on analysis ash values from 0·1–50·0%).

Moissan's Experiments

With a view to ascertaining the physical connection between "amorphous" carbons and graphite Moissan,[6] inspired by Berthelot's work, carried out a large series of experiments with the following objects :—

(1) to establish the relationship between carbons and graphites as regards their physical and chemical properties by producing graphite artificially, to compare its properties with the natural product, and to ascertain what physical or chemical conditions are necessary to transform the "amorphous" carbon to the crystalline form ;

(2) to study the effects of various chemicals on the three forms of carbon postulated by Berthelot viz : "amorphous," graphitic and diamond ; and

(3) to confirm and extend the work of Berthelot and others on the properties of diamond and to try and produce this material artificially.

Moissan found that there were noticeable differences in the specific heats of the three allotropes (diamond = 0·14, graphite = 0·17, wood charcoal = 0·20 cal./g.).

Fairly pure forms of carbon were first made from lampblack, by heating petroleum oil at 500° C. and washing with benzene, alcohol and ether, followed by drying at 150° C. This material had a specific gravity of 1·83 and on analysis was found to contain 93% carbon and 0·3% ash, the balance being oxygen and hydrogen. Combustion in oxygen started at 371° C., but higher temperatures were obtained after prolonged heating at 910° C. in a *closed* crucible.

Then, by burning pure acetylene, a carbon was produced which was somewhat purer than the previous lampblack, and the combustion temperature in oxygen of this material was 375° C. Various other carbons were made from starch and sulphuric acid, from anthracene and ferric chloride, by heating carbon tetrafluoride and tetra-iodide, and by reduction of carbon dioxide by metallic boron. In all these the carbon was considered impure, as it contained about 1% each of ash and hydrogen.

Berthelot[7] suggested that carbon was never produced in its natural state (i.e. as graphite) by any low temperature reaction, and that carbon was not, therefore, comparable to an element but was rather "an extremely condensed carbide low in hydrogen content." Moissan's experiments, which tended to give a polymerised product whose density was always less than 2, appear to have confirmed Berthelot's postulation.

Artificial Graphite

The experiments on the manufacture of artificial graphite, and some of the findings, are summarised below :

(1) heating diamond in the electric arc resulted in a graphite product which analysed 99·88% C and 0·016% ash, and responded to Brodie's test giving yellow graphitic oxide :

(2) sugar carbon and wood charcoal heated in an arc furnace to a high temperature formed a graphite similar to, but slightly less pure than, that referred to in (1) ;

(3) electrode ends used for striking the arc were found to be similar to the graphite made from diamond ; and

(4) solution of sugar carbon in various molten metals resulted in "crystallisation" of graphite on cooling. Of the metals used—aluminium, silver, manganese, nickel, chromium, tungsten, molybdenum, uranium, zirconium, vanadium, titanium and silicon—manganese was most consistent in giving shiny hexagonal plates. The other metals gave irregular crystals, but all gave yellow graphitic oxide with Brodie's test. Specific gravities varied from 2·10 to 2·25, and the combustion temperatures in oxygen were all about 660° C.

Since it was found that the stability to oxidation treatment (Brodie's test) increased with increase in temperature of formation of the graphite, there must be several forms of graphite as there are several forms of "amorphous carbon." This led to a study of the effect of temperature and pressure on graphite formation and for this only one metal (iron) was chosen as the medium

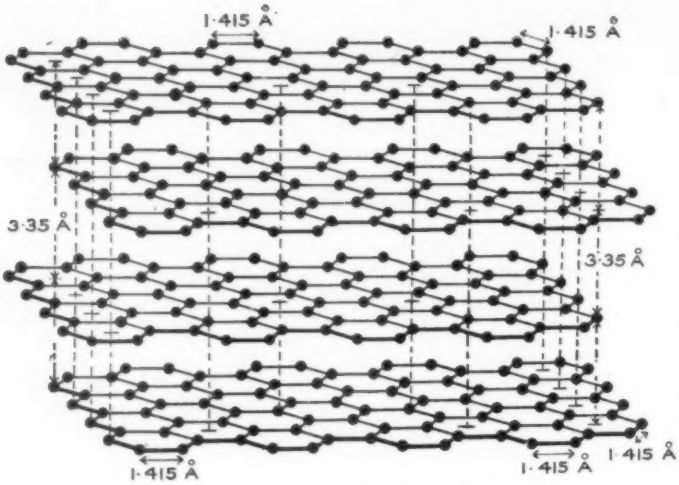


Fig. 1.—The graphite crystal lattice according to Bernal (layer planes stacked as in Fig. 2).

for carbon solution. Earlier work on grey cast iron (M.P. 1,150° C.) dissolved in hydrochloric acid, or treated with aqueous iodine solution (Eggertz), or with aqueous copper sulphate solution[8], gave a mixture of carbon and graphite (by Brodie's test).

Soft iron was heated in a sugar carbon crucible at approximately 2,000° C., and on cooling gave brilliant black regular hexagonal crystals of very pure graphite (C = 99·15%) of specific gravity 2·18, the combustion temperature in oxygen being 650° C.

To test the effect of pressure, a repeat experiment was cooled rapidly by plunging into cold water. Smaller crystals were produced but the properties were similar to those obtained previously.

In all cases of graphite formation by precipitation from a molten metal on cooling, the metal is removed by dissolving in appropriate acids. This leads to the presence of hydrogen in the graphite, as shown by its evolution on heating the graphite to 500° C. in vacuo. The gas is not chemically combined with but occluded or adsorbed by the graphite.

Properties of Diamonds

Early attempts to produce artificial diamonds, from Gannal in 1828 to Hannay[9] in 1880, were abortive and incapable of repetition by Moissan and others, but Marsden[10] is said to have produced very small " black " diamonds by the rapid cooling of molten silver heated to 1,550° C. in a sugar carbon crucible. This was confirmed by Moissan, using iron instead of silver and heating to 3,500° C., followed by plunging into cold water. On dissolving the iron in hydrochloric acid he obtained graphite and both " black " and transparent diamonds of very small size. (This was confirmed in 1917 by Crookes, La Rosa, Ruff and others).

Researches in those early days on natural diamonds showed that :—

(1) combustion in oxygen started at 750°–875° C. depending on the specimen used ;

(2) heating in hydrogen to 1,200° C.[11] resulted in no change in weight ;

(3) heating in fluorine[12] had no effect on diamond, but graphite and lampblack were attacked at 600° C. and room temperature respectively ;

(4) dry chlorine and hydrofluoric acid gas had no effect at 1,200° C. ;

(5) with sulphur vapour at 600° C., attack was slow but sodium vapour had no effect ;

(6) molten iron and platinum separately combined easily with diamond ; and

(7) molten sodium or potassium carbonate reacted with it at 1,200° C. with the evolution of carbon monoxide.

Berthelot[13] had shown that a diamond must possess the following important features for classification :—(*a*) maximum hardness (10 on Moh's scale) to scratch all else and not be scratched itself ; (*b*) have a specific gravity of 3·5 ; and (*c*) burn in oxygen at 750° C. to give 3·666 times its weight of carbon dioxide.

Moissan modified this to the effect that *all three* properties must be possessed by the substances before they could be called diamond, for he showed that hardness alone was unreliable, since boron and titanium carbides would scratch the diamond, and a specific gravity of 3·5 could be possessed by some very hard substances such as those mentioned.

It may be concluded as a result of these experiments that it is very difficult to prepare a pure sample of " amorphous " carbon since organic substances decomposed by heat seem to retain combined oxygen, nitrogen, hydrogen or sulphur, which may only be removed by prolonged heating at temperatures in excess of 1,000° C., under which conditions some graphite will probably be produced. Most " amorphous " carbon materials (charcoals—from wood, bone and sugar ; lampblack—from gases and oils ; and coke or coal) have a specific gravity of less than 2, a low ignition temperature in oxygen (about 300° C.), and do not give yellow graphitic oxide when tested with Brodie's mixture.

Graphite is a crystalline form of carbon which has a specific gravity of about 2·2 and an ignition temperature in oxygen above 600° C. In this respect, the reactivity to oxygen increases with increase in temperature of formation (as applied to artificial graphite made from carbon substances). Most natural graphites contain small proportions of occluded gases (which may cause swelling on heating) and mineral impurities. Artificial graphites may be much purer in these respects, especially when produced at very high temperatures. In all cases they give yellow graphitic oxide.

Natural graphites are found frequently in surface rocks, and may therefore be presumed to arise as a result of comparatively low pressure reactions. On the other hand, diamond deposits are usually found at great depths and diamond is undoubtedly the high pressure modification of carbon : this was confirmed by Moissan's experiment. Diamond has a specific gravity of 3·5 and an ignition temperature in oxygen about 800° C. It does not give graphitic oxide when treated with oxidising acid mixtures.

Investigation of Atomic Structure

Many of these facts have now been investigated by means of special experimental techniques such as X-ray and electron diffraction, controlled decomposition of carbon bearing gases, and reactivity to chemical oxidation.

In the last 40 years, much work has been carried out with the X-ray powder camera with a view to

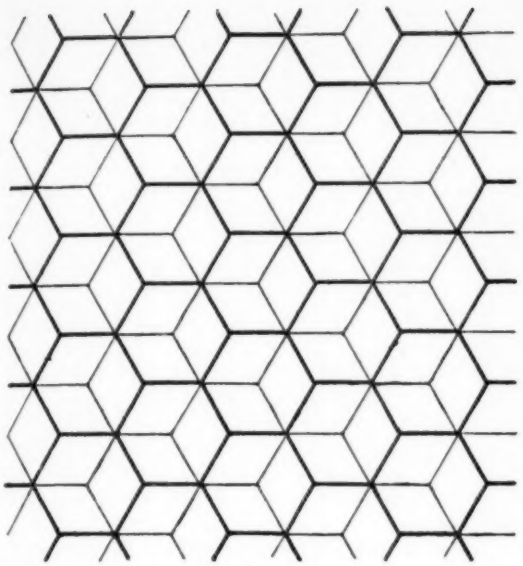


Fig. 2.—The stacking of the layer planes. The hexagon net drawn in thick line represents one layer plane, and that in thin line the relative position of the parallel layer planes above and below it.

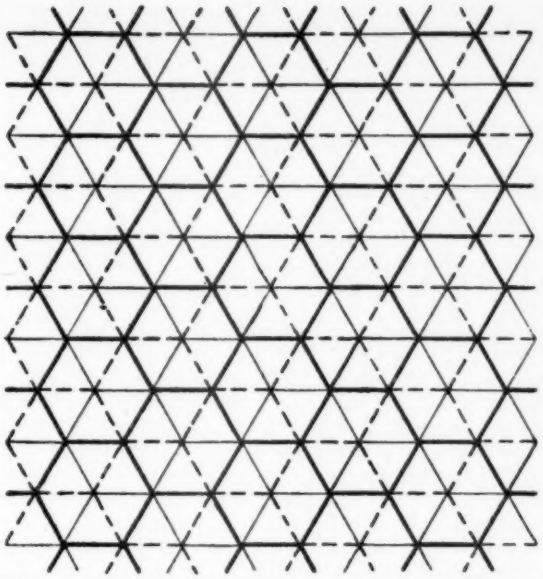


Fig. 3.—The stacking of the layer planes according to Lipson and Stokes. The hexagon nets drawn in thick, thin and broken lines represent respectively the relative positions of the sequence of parallel layer-planes in the lattice.

ascertaining the crystal structure of the various forms of carbon, and from the results obtained attempts may be made to explain some of the phenomena observed by the early workers, and to account for many of the diverse properties possessed by the different allotropes.

Bragg,[14] in 1913, determined the distance between the cleavage planes of the graphite lattice as 3·42 Å, and the next year Ewald, from Laue photographs, found that the lattice was hexagonal with an axial ratio of 1·633. In 1917 we find recorded that Debye and Scherrer,[15] using X-ray diffraction, showed that a sample of "amorphous" carbon was, in fact, microcrystalline, and its lattice was of the type then proposed for graphite—hexagonal plates of atoms stacked above one another. They pointed out that the state of subdivision observed could not be reproduced mechanically.

Hexagon Layer Lattices

Bernal,[16] in 1924, first suggested the honeycomb layer structure for graphite with carbon atom spacings in the hexagon layers of 1·415 Å and the distance between layer planes equal to 3·35 Å. It will be seen from Figs. 1 and 2 that the Bernal lattice has each hexagonal carbon atom layer parallel to the next, but in such a way that one half of the atoms in one layer lie normally above one half of the atoms in the layer beneath, whilst the other half of the atom layer is normally above the centres of the hexagons of the layer below, i.e. that *alternate* layers of atoms correspond. Furthermore, the bonding forces of the carbon atoms in the layer planes are the very powerful co-valent valency forces (more powerful than in the diamond), but the interplanar binding forces are very weak. This feature probably accounts for the anisotropic properties of graphite, since it has been shown[17] that electrical conductivity is greater in directions parallel to the layer planes than at right angles to them, and similar effects are shown by thermal conductivity and linear expansion measurements.

After confirmation by Hassel, Mack, Mauguin and Ott independently, the Bernal lattice was widely accepted until doubts were cast by Finch and Wilson[18] and also by Laidler and Taylor.[19] Both research teams, using electron diffraction techniques, found faint lines on their powder photographs of both natural and artificial graphites which did not correspond with the planes of atoms in the postulated Bernal lattice. So Lipson and Stokes,[20] working on the assumption that the samples investigated consisted of two forms of graphite, proposed a modified lattice (Fig. 3) in which, although the carbon hexagons have shared edges, the stacking of hexagon plates in layers are such that they are *not* symmetrically disposed in *alternate* layers (as the Bernal lattice) but that every third layer is symmetrical on the "*a b c*," "*a b c*" sequence.

This modified lattice, they suggested, may be considered to be a composite made up of about 80% of the Bernal lattice, 14% Debye-Scherrer structure and 6% disordered or turbostratic.* A similarity will be noticed between the positioning of hexagon layer planes and the close packing of spheres in the face-centred-cubic lattice. The Bernal lattice corresponds to the sphere packing arrangements in a hexagonal-close-packed lattice.

As yet, the graphite lattice is still not proven, but from electrical, magnetic and mechanical properties, the suggested arrangements of carbon atoms in hexagon layers is undoubtedly correct, although the disposition of the layers has yet to be finalised.

"Amorphous" Carbon Structure

Much conflicting data has been obtained by various workers on the possible arrangements of carbon atoms in

* Biscoe and Warren[21] coined the word "turbostratic" for the description of hexagon layer planes parallel to each other in one crystallite but randomly orientated otherwise, with layer spacing equal to or greater than that normally found in the graphite crystal.

"amorphous carbons." Many think, as Debye and Scherrer, that these materials are microcrystalline with the same type of lattice as the layer type lattice propounded by both Bernal and Lipson, but others modify this idea to the extent that the structure is not at all regular, but rather a disordered array of minute graphite type crystallites.

This may be substantially true for carbons deposited from a gas phase (from carbon monoxide or hydrocarbons),[22] but carbon prepared by carbonisation (condensed phase) is undoubtedly influenced by the structural characteristics of the parent carbonaceous material, and in many cases a disordered cross linkage of lameller carbon planes have been observed, together with proportions of "normal" (Bernal) or of Lipson-type lameller structure.

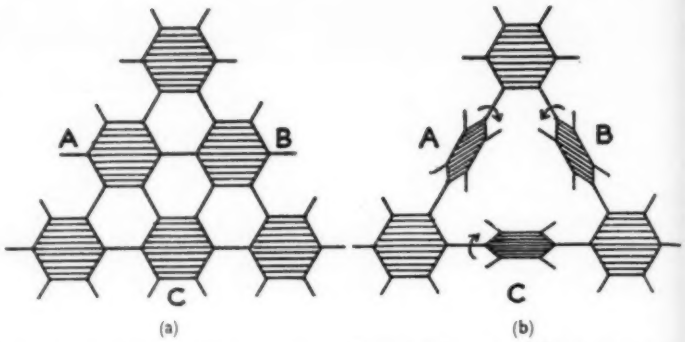


Fig. 4.—Diagrammatic representation of tilting of alternate hexagon rings of layer planes.

Quite varied experimental data lend support to this concept. X-ray diffraction photographs of various "amorphous" carbons[23] from carbohydrates and bitumens have given a distorted cylindrical pattern with the *c*-axis (height) tending to increase at a greater rate than the *a*-axis (diameter) with increasing temperature of carbonisation. This distortion is attributed to the presence of residual foreign atoms (oxygen, hydrogen, nitrogen, sulphur) from the parent carbonaceous material in the lamellar-like graphite lattice. Further investigations on various organic compounds have given evidence of a disordered cross-linked carbon layer system existing.

Cross-Linked Structure

These workers[23] therefore postulate that although to date only two carbon lattices are known, that of the diamond and the layer lattice of graphite, there may be a third possibility, with a variation in the carbon atom arrangement in the graphite layer lattice, which can be constructed from the graphite lattice by considering an inward tilting through 60° of alternate hexagonal rings of layer planes (after breaking valency bonds), so that they link up with layers above and below to give a rhombohedral lattice with little evidence of flat layer planes as exist in the original graphite lattice. It has been shown that such an arrangement gives little lattice strain, since the valency bonds may be easily re-made to similarly tilted hexagons in the adjacent planes above and below.

This idea is shown diagrammatically in Fig. 4, and, from models, in Figs. 5 and 6, where Fig. 5 shows the relationship of this proposed lattice to that of graphite, and Fig. 6 the rhombohedral cell of the resulting lattice after the tilting of the layer planes and the restoration of valency linkage. Supporting evidence for this proposal has been obtained by Karle and Brockway[24] from electron diffraction studies on carbons obtained by thermal decomposition of various organic compounds.

It would seem that the difficulty in assessing the correct structure for carbons is tied up with the difficulty in preparing a *pure* sample of carbon, since organic substances decomposed by heating seem to retain some of the chemically combined oxygen, nitrogen, hydrogen or sulphur which may only be removed by prolonged heating at fairly high temperatures (above 1,000° C.) in inert atmospheres or *in vacuo*, and this treatment has been shown to cause some graphite formation. Thus, it is very difficult to obtain a pure representative sample of a true "amorphous" carbon, since the presence of these foreign atoms appear to distort the parent carbon lattice.

From the foregoing considerations, therefore, it is only possible to suggest likely crystal structures for carbons. There are two possibilities :—

(*a*) a "turbostratic," disordered graphite-like layer structure ; or

(*b*) a three dimensional, disordered cross-linked structure ;

and in general it is thought that both types exist in varying proportions in the various carbons which may be produced from a host of organic substances.

Evidence points to the purer carbons (such as those deposited from a pure gas, e.g. carbon monoxide) having a preponderence of structure (*a*), whereas the carbons produced by carbonisation of carbohydrates have a larger proportion of structure (*b*).

This existence of varying proportions of mixed structure may well explain the diverse properties possessed by the various carbons, such as their gas absorption, rubber filling and graphitising propensities, and their specific gravities, electrical conductivities and mechanical properties.

Graphitic Oxide Test Not Specific

When treated by Brodie's reagent, some apparently "amorphous" carbons yield high percentages (up to 87%) of graphitic oxide—compared with 92% with Acheson electrographite and 95% with Ceylon natural graphite. Although this test was considered specific for graphite by Berthelot and others, it has been shown subsequently[25] that the effect of this oxidising mixture depends on crystal size and state of atom packing in the carbon treated. Thus, it is possible for apparent carbons

TABLE I.—EFFECT OF CHEMICAL OXIDATION ON THE VARIOUS FORMS OF CARBON

Substance	Oxidation Rate (ml. CO_2 evolved from 1 g. in 2½ hours)
Sugar Charcoal	42
Diamond	43
Low Temperature Cokes	75–105
Metallurgical Cokes	104–220
Wood Charcoal	328
Large Electrode Carbons	564
Natural Ceylon Graphites	824–1,043
Acheson Electrographite	1,006–1,259

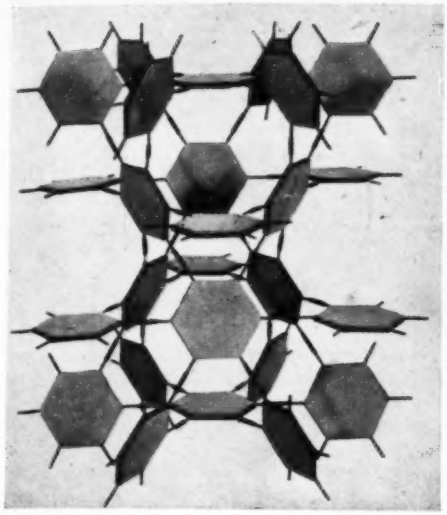
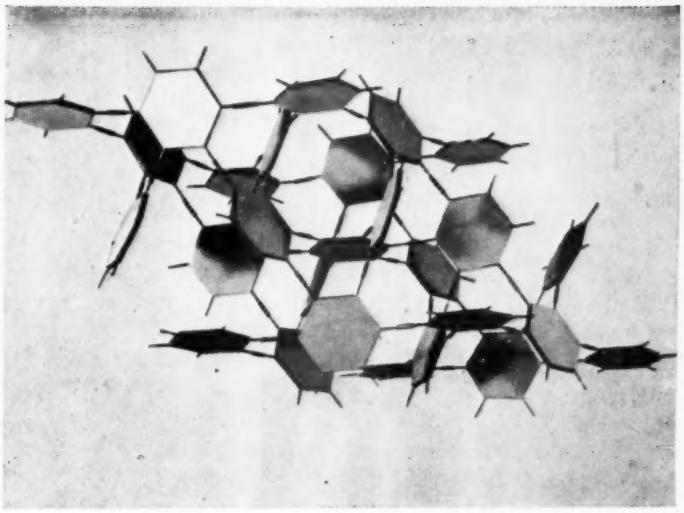


Fig. 5.—Model showing the relationship of the lattice produced by the tilting of alternate hexagon rings in relation to that of graphite.



Courtesy of the Chemical Society

Fig. 6.—The rhombohedral cell of the resulting lattice after the tilting of the hexagon rings and the restoration of the valency linkages.

to give end products in the test which resemble those associated with graphites.

The swelling property of certain graphites when treated with oxidising acid mixtures, or during electrolysis, is now thought to be due to penetration between the hexagon layer planes of various ions (e.g. (SO_4) with sulphuric acid), or oxygen, or even sulphuric acid molecules, to give compounds such as the oxide and bisulphate of graphite. Other similar salts are known—nitrate, perchlorate, phosphate, arsenate and the halides. This intercalation may cause the inter-layer spacing of the carbon hexagons in the graphite lattice to grow from 3·35 Å to about 8 Å.

On this question of oxidation response there arises evidence of an unusual nature. Considering reactivity to oxygen, it seems conclusive that " amorphous " carbons have a lower ignition temperature (about 300° C.) than have graphites (above 600° C.), and this is thought to be due to the presence of residual combustible hydrocarbons in the " amorphous " carbons which start the ignition at a low temperature, since carbons produced at high temperature have ignition temperatures approaching that of graphite. Furthermore, certain catalysts (such as 2% sodium carbonate) increase oxygen reactivity of carbons to an even greater degree—this soda treatment of domestic coke for easier combustibility is common practice—but has little effect on graphites.

With chemical oxidants, however, such as nitric or sulphuric acid, nitric acid and potassium chlorate (Brodie's reagent), or fused sodium sulphate, the reactivity is usually greatest with graphites, and at one time this was thought to be due to the relative carbon crystal sizes involved (micro for " amorphous " carbons and macro for graphites). Riley[27] and others state, however, that since oxidation rates (as determined by the volume of carbon dioxide evolved), by a chromic-phosphoric acid mixture, of many graphites are greater than those of a wide selection of carbons, it is undoubtedly due to the fact that the oxidant can open up the layer structure of the graphites more easily than the cross-linked turbostratic structure which has been proposed for " amorphous " carbon. The experimental results are set out in Table I.

Thermal Stability

Despite the weak forces between layer planes, the melting point of graphite is very high, indicating great stability in the carbon layer planes. Various melting point figures are quoted in the range 3,760–3,800 ± 100° K when using a hydrogen atmosphere at a pressure of 800 mm. mercury. With lower pressures, the boiling point precedes the melting point and sublimation occurs.

Further evidence of the thermal stability of carbon (" amorphous ") is shown by the slight evidence of crystallisation at temperatures below 1,500° C.—usually temperatures approaching 3,000° C. are necessary to complete the conversion to graphite. This was realised over fifty years ago when Acheson[26] found that graphite could be most easily produced from carbonaceous materials after allowing them to combine chemically with mineral matter such as silica, alumina, clay, lime, ferric oxide, etc., and then subjecting the mixtures to high temperature, when dissociation of the unstable carbon compounds (thought to be the carbides or oxycarbides of silicon or other metals) would occur and graphite result. Similarity with Moissan's early experiments for the production of artificial diamonds will be noticed.

It has also been shown that carbon deposited from a gas phase [$2CO = C + CO_2$] by a catalyst at low temperatures (350°–550° C.) is highly crystalline, and must be due to the attachment of carbon atoms (from the gas) to some preformed graphite nuclei.

Diamond Structure

Before concluding this section and to complete the picture, a brief mention of the diamond is necessary. In contradistinction to the other two allotropes of carbon, the diamond lattice is well established. It

Fig. 7.—The crystal structure of the diamond, showing how each atom has four equidistant neighbours.

can best be described as belonging to the cubic system with each carbon atom joined to four others by valency bonds arranged tetrahedrally. The distance between carbon atoms is 1·54 Å, and the distance apart of the hexagon rings is 2·51 Å. Fig. 7 shows the structural arrangement of the carbon atoms in the diamond lattice. The properties of high hardness and melting point are attributed to this stable carbon linkage.

Diamond shows a greater resistance than either carbon or graphite to most chemicals and a higher ignition temperature in oxygen (about 800° C.). On heating in the electric arc with the exclusion of air, graphite is formed. It would, therefore, appear that graphite is the stable form of carbon at high temperature with normal pressures.

Comparative physical properties of the three forms of carbon will be found set out in the accompanying Table II.

As a result of this discussion on the constitution of the allotropic forms of carbon it will be possible to follow more clearly the reasons why carbon in any particular form is necessary for a particular purpose or to give certain properties.

This will be evident when the industrial carbons and graphites, the manufactured products using these raw materials, and the applications for which they are most suited are considered in subsequent articles of this series.

TABLE II.—AVERAGE VALUES FOR SOME PHYSICAL PROPERTIES OF THE VARIOUS FORMS OF CARBON (VARIOUS SOURCES)

Property	Diamond	Graphite	Carbon
Density (g./cu. cm.)	3·52	2·1–2·6	1·3–2·0
Ignition Temperature in Oxygen (°C.)	750–900	650–700	300–450
Thermal Conductivity (cal./sq. cm./cm./sec./°C.) at 20° C.	0·35*	0·30	0·016
Specific heat (cal./g.) at 25° C.	0·12†	0·17	0·20
Heat of Combustion to CO_2 (cal./g.)	7,824	7,796 natural graphite 7,762 electro-graphite	7,912
Coefficient of Linear Thermal Expansion $\times 10^{-6}$ (per °C.) at 20° C.	1·45*	1·8‡	2·3‡
Specific Resistance (ohm-cm.) at 20° C.	10^{12}–10^{13}†	0·0015	0·0050

* "Industrial Diamond Review" Data Sheet 6a (New Series), 1948.
† Kaye & Laby, "Physical and Chemical Constants" (Longmans Green), 1941.
‡ Data supplied by the National Carbon Co. (U.S.A.).

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New Foundry Plant Filmed

A comprehensive pictorial record of all stages in the production of blackheart malleable iron castings is contained in a special film entitled 'Modern Malleable' made at the Tipton foundries of Messrs. Hale and Hale, Ltd., one of the largest producers of malleable iron castings in the country. It is a 16 mm. sound film in black and white, with a running time of 32 minutes.

The film will be loaned free to technical bodies, recognised institutes and associations, schools and universities, apprentice associations and industrial concerns interested in the use of ferrous metals. Those interested in loaning the film should apply to Messrs. Hale and Hale (Tipton), Ltd., Dudley Port, Tipton, Staffordshire.

Change of Address

THE London Office of Newman Industries, Ltd. has been moved from 49, Park Lane, W.1 to Terminal House, Grosvenor Gardens, S.W.1 (Tel.: Sloane 8206).

Correspondence

Arc Furnace Electrode Control

The Editor, METALLURGIA.

Dear Sir,

In the June issue you have an article on "Hydraulic Arc Furnace Electrode Control" which, it is claimed, is superior to other methods at present in use. When, however, the statement is made that inferior results are obtained mechanically by electro-magnetic regulators of the rotary amplifier type, we feel that some protest is justified. We installed a number of arc furnaces during the last war with hydraulic electrode control, but abandoned these in favour of the rotary amplifier regulator because of the maintenance difficulties experienced by our customers. In many instances regulators of this type have been replaced by others of the rotary amplifier type with improved results in every case.

Undoubtedly, hydraulic regulators have advantages, but we feel that their use will not be advanced by condemnation of other types without factual evidence.

Yours faithfully,

J. E. GAMAGE.

Electric Furnace Co., Ltd., Weybridge, 9th July, 1953

Metal Casting Methods

V—Non-Ferrous Ingots

By J. B. McIntyre, M.Sc., A.I.M.

Senior Lecturer, The National Foundry College, Wolverhampton

Continuing this series of articles on metal casting methods, the author discusses the casting of non-ferrous ingots, with particular reference to copper-base alloys, which are mainly cast in batch-type moulds, although the continuous casting process is now being introduced for this purpose.

REFERENCE was made in an earlier article of the series to the continuous casting process, which plays such an important role in the production of light alloy ingots for subsequent working. Although the process is now used for copper-base alloys, its application in this field is much less widespread than is the case with light alloys, and the majority of brass and bronze ingots are cast in chill moulds of one type or another.

Copper Ingots

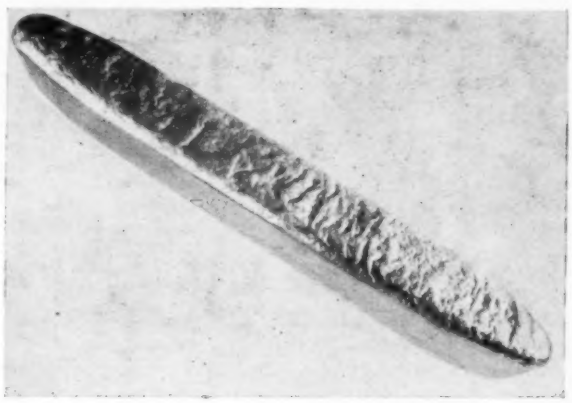
Large tonnages of copper are cast into wire bars, slabs and ingots, the tough pitch variety being commonly used for such purposes. Tough pitch copper may be regarded as commercially pure copper which contains a limited amount of cuprous oxide. In the melting and casting process, the cuprous oxide in the copper reacts with hydrogen in the furnace atmosphere, forming steam, which is trapped in the copper during the rapid solidification process, and is dispersed throughout each casting. Apparent shrinkage is reduced to negligible proportions by a mechanism similar to that operating in rimming steel, though segregation is obviously not a factor in a pure metal.

Tough pitch copper ingots and slabs may be used direct, without any shearing or fettling, since the porosity is very widely dispersed. Wire bars, on the other hand, are usually planed or scalped before use, to remove the high concentrations of cuprous oxide which are liable to occur in the surface layers of cast material. A certain amount of deoxidised copper is produced, in which the oxide content is removed by means of a preliminary deoxidation treatment before casting. Such material pipes deeply, and is usually cast into billet moulds; the product is used for extrusion purposes.

Cast iron was originally used as a mould material for casting copper ingots, but was limited in application, since poor casting surfaces were obtained. Copper inserts were adopted almost a hundred years ago, and wholly copper moulds are now used in general practice: these may be either solid or water cooled. Small copper refining plants use the former type, whilst the latter find application in large scale installations.

Casting in Copper Moulds

Solid copper moulds are made in a very simple manner. Cast iron or rolled steel segments are placed together, so that the required mould outline is obtained, and the assembly is placed on a cast iron or copper slab of substantial thickness. Molten copper is poured into the cavity, and pressure is applied to the metal surface by means of a mould press assembly. The latter is simply



Tough pitch copper wire bar.

a smoothly finished casting which is mounted on a press head, and may be an ingot, slab, or anode, as required. A negative impression is obtained in the copper mass contained in the mould when solidification is complete. The solid copper mould may then be put into service; liquid copper is cast into the mould cavity and the ingot, slab, or anode produced bears as a positive impression the detail which may be required. An aqueous suspension of bone ash is widely used as a refractory dressing both for mould and casting production.

In practice, the moulds are filled by hand, and when the castings are solid, the mould and casting are inverted, so that the latter is precipitated into a water bath or bosh. The mould assemblies are mounted on trunnions for ease of handling. When the useful life of the mould has been reached, it is usually found that casting and mould cannot be separated; both are then remelted, and a new mould is substituted.

When wire bars are produced on a larger scale, the solid moulds are mounted on a casting wheel of the Walker or Clark type. Casting wheels consist essentially of a central hub, bearing a number of metal arms arranged in cantilever fashion. Each arm bears a trunnion, which serves as a hinged mounting for the mould assembly. In practice, the wheel is slowly rotated in the horizontal plane, so that empty moulds are brought in turn under the stream of liquid copper. After filling, each mould is allowed to continue its journey round the circle until the casting is completely solid, when it is discharged into a water bosh. Where necessary, cooling may be accelerated by means of water

sprays directed onto the mould assemblies. The wire bar moulds may be of single or multiple cavity design, and water-cooled copper moulds may be used on the casting wheels if very large outputs are needed and normal cooling methods prove impracticable.

Difficulties with Non-Ferrous Alloys

Non-ferrous alloys require a somewhat different casting technique from that used for pure metals such as copper. Most of the non-ferrous alloys in common use are liable to dross formation or gas solubility effects which may adversely affect the surface finish or soundness of the cast material. Ingots, which form a large proportion of the non-ferrous alloys cast, may be subsequently wrought, and it is vital that good surface finish and adequate internal soundness should be maintained. Poor surface finish on cast non-ferrous alloys may be due to the presence of entrapped oxide films, skin blowholes, or cold laps and cold shuts.

The first of these defects is of a metallurgical character and is characteristic of the particular alloy in which it occurs. Molten alloys containing aluminium or chromium are coated with oxide films of an adherent nature, and such films are almost impossible to remove completely by such methods as skimming, etc. Unless non-turbulent pouring methods are used, these films may be present at a considerable depth in the castings, and may not be removed even by heavy machining. Alloys containing zinc may have a light coating of zinc oxide on the surface, but this is not so readily entrapped in the castings.

Surface porosity arises chiefly from corrosion products on the mould, from moisture condensed on the walls, from residues that have collected in cracks in the mould walls, or from using unsuitable mould dressings. It may also occur as a result of reaction between the carbon in the cast iron of the mould and any oxygen or oxide present. Surface exudations such as "tin sweat" frequently occur in phosphor bronzes, and it may be necessary to machine away the 'blebs' before working the ingot. The incidence of this feature may be regulated by casting practice, by controlling the gas content of the alloy, or by arranging that the rate of cooling is as unidirectional as possible.

Casting tin-bronze ingots.

Gas Porosity

Gas solubility is a major cause of internal unsoundness in many non-ferrous alloys. The gases concerned may be elements, such as hydrogen, or compounds such as steam and sulphur dioxide. Element gases are usually rejected from solution as the temperature of the melt decreases: it has been shown by Smithells[1] that hydrogen is readily soluble in most molten metals, and in many non-ferrous alloys. In most cases, gas solubility increases with temperature. When the vapour pressure of the molten metal reaches a sufficiently high value, a decrease in the gas partial pressure occurs and the amount of gas in the metal falls.

Hydrogen need not cause serious unsoundness, provided that the metal solidification rate permits the gas to escape freely, but compound gases are more likely to lead to trouble of this nature. Allen and Hewitt[2] have shown that steam unsoundness in tough pitch copper is due to the reaction which occurs between dissolved oxygen and hydrogen during solidification :—

$$2\,H_2 + O_2 \rightleftharpoons 2H_2O.$$

According to the law of mass action, the hydrogen and oxygen concentrations in molten metal at a given temperature are related to each other, and to the partial pressure of the steam in the surrounding atmosphere. The concentrations are given by :—

$$[H]_{(metal)} = K\sqrt{\frac{p_{H_2O\ (atmosphere)}}{[O]_{(metal)}}}$$

where K is an equilibrium constant which decreases with temperature. Since both hydrogen and oxygen are less soluble in solid copper than in the liquid metal, a concentration of both gases is built up in the liquid phase during solidification, until the equilibrium product is finally exceeded, and steam unsoundness appears. Pearson, Baker and Child[3] have shown that a somewhat similar process may cause unsoundness in alloys containing nickel, carbon and oxygen being the essential reactants in this case.

The various reactants discussed are believed to originate mainly in the atmosphere prevailing in ordinary fuel fired furnaces. Though moist charge materials are frequently quoted as a source of gas absorption in non-ferrous melting practice, it is unlikely that these are a major source of difficulty, except in light alloy practice. In copper-base and nickel-base alloys, practically all the moisture present is likely to be driven off before the charge materials have reached the melting temperature.

Gas Removal

Though reaction gas unsoundness is usefully applied in tough pitch copper production, it is not always desirable in other cast material such as shaped sand castings. In tin bronze melting practice, for example, this defect is avoided by means of an oxidation treatment which is sufficient to remove hydrogen as steam continuously throughout the melt. The excess of oxide is then removed from the melt by a deoxidation treatment before casting. This method has been applied to the production

of shaped castings in high conductivity copper, by the writer, and tin bronze production technique has been discussed in detail by Baker and Child[4], and Pell-Walpole. Mould reaction techniques have been successfully applied in the production of pressure-tight castings.

Reaction gas unsoundness is not a problem in non-ferrous alloys of high zinc content, since the high vapour pressure of the latter constituent effectively prevents gas absorption. Aluminium alloys are prone to gas unsoundness, as the water vapour present during melting reacts readily with molten aluminium, forming alumina and hydrogen. The oxide is insoluble in the melt, while hydrogen is readily absorbed, and special techniques have been established to prevent pinhole formation in aluminium alloys. Such methods involve the removal of hydrogen from the melt by purging with a stream of chlorine or nitrogen before casting. Bailey and Baker[5] have stated that the mechanism of degassing must be mechanical, since no chemical combination appears to be possible.

Alloys such as nickel silver are liable to gas unsoundness despite the comparatively high zinc content of such material. This is due to the equally high nickel content, which promotes the absorption of hydrogen. An oxidising treatment, followed by deoxidation before casting, appears to be effective.

Dross Formation

Non-ferrous metals and alloys are usually top poured, provided that the material concerned is not liable to be adversely affected by such treatment. The technical advantages attached to top pouring methods have already been discussed in steel ingot casting, and the same factors are operative in the non-ferrous field. In many cases, however, dross formation is an additional problem, one which is even more important in the production of sand castings than it is in the case of chill castings, and this problem will be discussed in some detail in a subsequent article.

Genders and Bailey[6] have shown, in a most striking fashion, that in top pouring continuous metal displacement may occur, and the first quantity of liquid metal which is poured into a mould may finally reach the upper portions of the casting before solidification occurs. It is apparent that metal casting methods which involve top pouring under pressure conditions will tend to promote turbulence and dross formation. Though bottom pouring technique has been tried on a limited scale for the production of ingots, slabs and billets in the non-ferrous field, this system finds most application in sand foundry practice.

A novel approach to the dross problem is that due to Durville[7], whose casting method was originally devised for the non-turbulent pouring of brass slabs for rolling, and has since found wide application in the aluminium bronze field. A typical Durville casting machine is illustrated, and consists essentially of a metal container, which may be in the form of a refractory crucible, and a mould assembly. The mould is inverted relative to the container and the axes of the two are parallel. Joining the mould and the container is a refractory lined channel and the whole rigid assembly is pivoted at the centre, so that it can be rotated in a vertical plane. In practice, the assembly is turned into a vertical position with the end bearing the metal container resting on the ground. A known quantity of molten metal is transferred to the container, and the assembly slowly turned over, allowing the metal to flow smoothly along the channel into the mould cavity. Since both mould and container are in precise alignment, no turbulence is possible, provided that the tilting motion is applied smoothly. Small Durville machines are operated by hand, while the larger type are tilted, either by gearing or hydraulic power.

Courtesy of J. Stone & Co., Ltd.

Durville casting of aluminium-bronze billet.

The Durville process is applied to the production of billets for rolling or forging, and, on a smaller scale, to the sand casting field. Billets are generally produced in cast iron moulds, which may be split longitudinally, or may be of the cannon type. The system is extremely simple and only a few limitations have appeared in practice. Smooth tilting is essential, to avoid ripple formation on the casting surface, and excess metal supply must be avoided, since that which is not received in the mould cavity will solidify in the runner system, or be deposited around the machine while still liquid.

The original Durville system allowed the mould and casting to remain undisturbed until completely solidified. This was a serious limiting factor in continuous operation, and each casting machine was immobilised for a considerable proportion of each day. A recent development[8] has removed this disadvantage, and rapid casting is now possible. The casting rate is very high, and pouring temperatures may be much lower than those used in sand foundry practice. Murphy and Callis[9] point out that ingots or billets having a greater length diameter ratio than 8 : 1 are not readily produced in the sound state, and Loiseau[10] states that a ratio of 6 : 1 is to be preferred for general practice. In Evans view[11] soundness may readily be obtained by the use of detachable copper plugs in the base of each mould.

Mould Dressings

Ingot mould dressings are seldom used in the Durville process, though they find wide application in the production of chilled phosphor bronze sticks, brass ingots and so on. The variety of preparations which are used and advocated as chill dressings for non-ferrous work is even greater than that encountered in steel ingot production. Pell-Walpole[12] has examined most of these preparations, and has made specific recommendations which are based on his experiments. These were carried out using the top pouring technique, with cast iron moulds split longitudinally. The writer repeated these experiments, using a cast iron mould which was drilled longitudinally, and adopting bottom pouring technique. It was apparent that the type of chill dressing and the method of application were not critical provided that adequate venting facilities were available. This applied especially to chill dressings which contained oils or greases capable of depositing carbon on the mould wall during the casting process.

Modified top pouring methods are frequently based on the tundish principle, in which the head of liquid metal is supported in a shaped container resting on the mould. One or more orifices are provided in the base of the tundish so that a steady flow of liquid material is introduced into the mould cavity. Such systems serve the dual purpose of directing the metal supply away from the mould walls—thereby preventing local overheating—and of gradually feeding shrinkage cavities as they appear in the casting.

Water-Cooled Moulds

The limitations of grey cast iron as a mould material for non-ferrous casting purposes are clearly seen when copper-base and nickel-base alloys are cast in such moulds. Barclay has shown that surface defects are liable to occur unless special precautions are taken during pouring. Genders and Bailey quote the following range of cast iron analyses which may be regarded as typical for non-ferrous mould material.

	per cent.
Graphitic Carbon	2·5 —3·1
Combined Carbon	0 —0·8
Silicon	1·5 —4·0
Manganese	0·3 —1·0
Sulphur	0·04—0·13
Phosphorus	0·14—1·2

These workers have shown that " blowing " is due to local gas evolution at the metal-mould interface, when cast iron moulds are used. This particular defect has not been found in non-ferrous material cast in other types of mould such as copper, graphite, or mild steel. Blowing is apparently due to local overheating during the actual casting operation, and is not easily avoided in the deep moulds of narrow cross section commonly used for brass slab casting. Mild steel and copper moulds are, however, liable to distort after a comparatively short life.

Junkers Moulds

The importance of brass slab castings as a main source of raw material for strip manufacture gave added interest to the problem of finding a suitable mould material for general purposes, and Junkers, in 1926, published a description of a water-cooled copper-faced mould which consisted essentially of thin plates of rolled copper, approximately ½ in. in thickness, bolted on to steel or cast iron covers. The mould assembly was designed to open on hinges in book fashion, and baffles were fitted between the copper face plates and the cast iron covers, to promote adequate water circulation for cooling purposes.

Junkers moulds were originally used in Britain for casting nickel silver, and have since been applied to the large scale production of brass slab ingots : more than 90% of the world output of wrought brass is originally cast in Junkers-type moulds. Brass billet moulds have been designed which consist of a seamless copper tube of appropriate wall thickness, which is sealed into a hollow cast iron casing provided with water circulation. Water-cooled moulds are usually treated with a mould dressing before use, and finely ground charcoal suspended in an oily vehicle is often used for this purpose. Cook and Fletcher have discussed the working life of water-cooled moulds, and indicate that failure, when it occurs, is mainly due to deformation in the copper face plates. Stresses are set up around the fastenings between face plates and backing materials, and bulging and small cracks may then appear, causing leakage.

Hessenbruch and Bottenberg, and also Oertel, have discussed the application of water-cooled moulds in steel production. This type of mould seems to be admirably suited to the production of billet or slab sized ingots, though it has not been adopted for such work on a commercial scale. The increasing cost of cast iron moulds and the large numbers which are required for steel ingot production should favour the introduction of Junkers type moulds. Cogging and slabbing mills would not then be needed in order to break down large ingots into smaller units for handling. The rapid cooling rate obtained in water-cooled moulds need have no ill effects upon the structure of the cast steel, since a reheating operation would normally be required before hot rolling.

Erichsen Moulds

In 1931, another type of water-cooled slab mould was introduced by Erichsen. This mould was similar in many respects to the Junker type, in that it was vertical and tundish pouring was used. Erichsen moulds were equipped with face plates of low conductivity steel instead of high conductivity copper, and special rubber jointing material was used to ensure flexibility between the face plates and the water-cooled jacket. It was claimed that during the casting the inner face of each face plate reached a higher temperature than the outer face which was water-cooled. Unequal expansion resulted, and the inner mould faces became convex, tending to exert pressure upon the cast slab or ingot during solidification. Liquid metal from the centre of the casting tended to rise into the upper shrinkage cavity, and piping was restricted. This was known as the Erical effect, and appeared to function efficiently in thin-sectioned castings such as brass slab ingots, but Genders and Bailey were unable to confirm that the metallurgical advantages claimed for this process did in fact exist. In 1938 Erichsen proposed that an alternative design should be considered, in which a horizontal metal frame of appropriate size should be fitted with a water-cooled copper base. External heating could be applied to the mould frame, and a flat solidification front promoted, whilst the shallow design would facilitate gas evolution, if required. Erichsen moulds have not been widely used, and the Junkers type has remained the most popular for the production of non-ferrous slab castings.

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B.I.S.R.A.'s North-East Coast Laboratories

Ironmaking Division's Field H.Q.

THE North-East Coast Laboratories of the British Iron and Steel Research Association, which are situated at Normanby, near Middlesbrough, came into operation in January, 1951. Their main task is to act as a base for field operations by research teams and to provide them with effective services. Their location, a few miles south of the Tees, puts them within easy reach of a number of blast-furnace plants which together make Teeside the largest iron-producing area in the country.

Besides field trials, experimental and pilot plant work is carried out, the latter being greatly facilitated by Messrs. Dorman Long & Co., Ltd.'s having made available a large building in their Redcar Works where experimental plants for pelletising and sintering have been built. In addition, a certain amount of original research is carried out at the Normanby laboratories. The work of the laboratory and its field teams is about evenly divided between ore preparation and the blast furnace itself.

Pelletising

In this process the ore is first ground almost as fine as face powder. It is then allowed to trickle into the top of an inclined rotating drum, and is sprayed with water, to which a binder has been added. As the drum rotates, the particles of ore form little balls, to which more ore sticks as they roll, thus increasing their size until they are nearly as big as golf balls. After screening at the lower end of the drum the larger balls are roasted in a kiln, to provide the mechanical properties they will require in the blast furnace. B.I.S.R.A.'s task was to establish a technique for dealing with the ores in actual or potential use by the British iron industry.

This has been successfully accomplished, and a ½-ton per hour pilot plant has been built and operated with various ores. In particular, methods of pelletising Sierra Leone and Syd Varanger concentrates have been worked out. These finely divided concentrates are likely to become available in increasing amounts during the next few years, rising to one million tons per year, and pelletising has been regarded as a possible method of agglomeration should these quantities overtax sintering capacity.

This has not yet become necessary, and as sintering capacity increases may never do so. The knowledge and "know-how" gained, however, are very far from wasted. They form a valuable reserve against future contingencies, with a pilot plant ready for trial operation with ores or concentrates of any type, British or foreign. Trials are in progress, for example, to test whether pelletising might be used for dealing with the residues from the dozen or so plants coming into operation in this country to manufacture sulphuric acid from iron pyrites. This residue is in the form of dust, and contains some 50–55% of iron—more than is contained in many foreign ores. Such a plant as B.I.S.R.A.'s pilot plant might well prove to be just about the right size to process the output of residues from each pyrites plant.

Sintering

The prospects of improved production held out by the extended use of sinter, and the urgent necessity of preparing much of the 10 million tons of iron ore imported into Britain each year, stimulates research on sintering. The increasing importance to the ironmaking industry of Britain is indicated by the production figures given below.

	Million Tons
1938	2·0
1948	2·9
1949	3·2
1950	3·4
1951	3·6
1952	4·4

There is a likelihood that this tendency will continue as plants now in building or projected come into operation.

It is not only to imported ores that the sintering process has been applied; considerable economies have been effected by sintering certain home ores. To make a ton of iron from home-produced ore in its natural state (containing about 30% iron) takes about 19–22 cwt. of high-grade metallurgical coke. The tendency of sintered ore to consume less coke in the blast furnace indicates the development of sintering into an integral part of the ironmaking process. The experience of the Appleby-Frodingham Steel Company in operating on almost 100% sinter burdens made from home ore, has shown that the elimination of volatiles, the reconstitution of the ore and the intimate mixing achieved by good sintering increase output and decrease fuel consumption. The saving in the blast furnace is about 5 cwt. of coke per ton of iron (17 cwt. against 22 cwt.). Against this the sinter plant consumes 4 cwt. of low grade coke breeze, a far less precious commodity than the metallurgical coke demanded by the blast furnace. The expansion in sintering capacity during the next few years may thus prove very large, and the importance of the development work on the process undertaken by the Association will no doubt be emphasized by the benefits arising from the improved design of the new plants.

The work on sintering has gone on at the same time as that on pelletising, much of it on the production plants

of member firms (particularly at Dorman Long's Cleveland Works), aided by trials on two small experimental sinter boxes at the Redcar works. The great advances thus made in the understanding of the sintering process have decreased the immediate importance of large scale pelletising, although there may be applications for which the latter is particularly suited. Incidentally, this work provides a good example of co-operation in research when the Association, financed by the industry as a whole to secure " background " knowledge for common use, solves on a plant established in one member's works, the problems encountered in another's and makes the answer available to all.

Importance of Permeability

Earlier work by B.I.S.R.A. field workers and the staffs of member firms established the important influence on quality of the carbon content and the thoroughness with which the materials are mixed. It has now been shown that, as far as output is concerned, permeability of the charge is of overriding importance in both the design and operation of sintering plants : when permeability is reduced, the rate of sinter output falls correspondingly.

Sintering consists essentially of burning a mixture of ironstone and fuel in a downdraught grate. Enough air must be drawn through the sinter mixture to complete the combustion, and the more suction required, the greater the horsepower needed to drive the fans that provide it. Tests carried out on commercial sinter plants and in the laboratory have shown that the amount of air required to sinter a mixture depends on the nature and proportions of the materials in it. If, however, any mixture can be made more permeable, more air can be drawn through the bed, using the same horsepower, the sinter burns more quickly and the speed of the moving strand can be increased.

At up-to-date plants, therefore, provision is made for continuous measurement of permeability, and operators are trained to correct variations. Suction measurement and air flow measurement devices are fairly easily installed and, given these, the operator reads off permeability by graphs or tables. A prototype meter is now being constructed that incorporates the two measurements and gives a direct reading of permeability. Fortunately, suction and thickness do not vary very much along a strand of sinter, and measurement is necessary only over a small section.

An illustration of the importance of permeability on output is provided by a Greenawalt sinter plant which showed a catastrophic drop in output when called upon to deal with Sierra Leone concentrates of a finer grade than usual. The cause was seen to be a decrease in permeability, and it was possible to carry out experimental mixes on the trial plant at the Redcar Works and show within a few days how the difficulty could be overcome. Permeability was restored by the use of crushed blast-furnace slag and closer moisture control.

The variable most easily controlled by the sinter plant operator is the amount of water. A very dry mixture takes a long time to sinter ; when water is added the permeability is increased and sintering is quicker. Too much water, however, decreases the permeability again and makes the sinter difficult to ignite. Measurement of permeability can give the operator a standard to work to in controlling the water feed.

Many other things affect the permeability ; they include the size and shape of the ore and coke particles, the proportions of these and of returned sinter and flue dust, and the way in which they are mixed. Permeability measurement gives the plant manager a quick assessment of the effects of changing the methods of mixing, the size of raw materials, the way they are discharged on to the strand, or the proportions of different materials in the mixture.

Permeability affects the speed with which air can be applied to the sinter mix. It does not affect the quantity of air required, which for a given mix is constant. The necessary quantity itself, however, can be affected by additions of lime, which does not in itself affect the permeability. The lime probably has the effect of making the coke burn more rapidly, so that the sinter gets hotter more quickly and the time for sintering is shortened and output is increased. This theory is supported by the fact that certain experimental mixtures, which would not sinter at all without lime, did so when it was added.

Application of the knowledge of sintering that has been gained by B.I.S.R.A. and by many individual firms (among them Dorman, Long & Co., Ltd., Stewarts and Lloyds, Ltd. and the United Steel Companies, Ltd.) has resulted in satisfactory effects upon output. For example, members of B.I.S.R.A. staff collaborated closely with the management and the scientific staff of a member firm in an attempt to increase production on a large existing sinter plant to 20,000 tons per week from a weekly production of 16,000 tons. Within six months 23,000 tons per week was reached, and this has been maintained and since considerably exceeded.

Increased knowledge of sintering also brings nearer the establishment of standards of economic design and operation, taking account of the conditions in which a particular plant has to operate. Here again measurement and calculation of permeability is of great importance, for such standards must be based on capital costs and on power costs in relation to the throughput of the plant, which in turn depends on bed permeability and the other factors affecting the resistance of the system. Comparison of existing or proposed designs of plant with the economic standards will indicate whether they are well matched to practice.

While work directed to the establishment of economic design standards is still in a tentative stage, it already indicates that some sinter plants may be too conservatively rated. Economic outputs from such plants could be markedly improved by the fitting of larger fans at a small fraction of the original capital cost.

Radioactive Tracer Techniques

Although the blast furnace has been in use for some 400 years, surprisingly little is known about what goes on inside it. This state of affairs is being gradually improved, and in this work the Ironmaking Division is playing an important part. Teams based on the Normanby laboratories have developed two exploration techniques using radioactive tracers which are yielding valuable information about blast furnaces, and which have been applied by B.I.S.R.A. research teams to furnaces in all U.K. ironmaking districts.

One of the factors which must have an important effect on the efficiency of the furnace is the gas transit time from tuyere to stockline, as this will influence the reactions taking place between the ore, the coke and the

oxygen in the blast. The period of contact of the ascending gas with the burden of the furnace is increased by high top pressure operation, and measurement of transit times under various conditions and in different vertical zones in the furnace should lead to a greater understanding of the operation of the furnace and to more efficient working.

Radon, the most readily available radioactive gas, has been used for the measurement of gas transit times. Forty millicuries of radon at a time, contained in some twelve gold tubes, each about ½ cm. long and ¾ mm. in diameter, are injected through one tuyere by an electric detonator and a ballistite charge which shatters the gold tubes and sweeps the gas into the furnace. Through a flexible metallic tube, above the stockline and vertically above the injection tuyere, samples of gas are withdrawn at one second intervals and subsequently analysed for their radioactive content. Examples of the use of this technique include the measurement and comparison of the transit times of the gases through the furnace, with and without bosh tuyeres, when the furnace was operated with different proportions of sinter.

The other radioactive tracer technique referred to above is used to determine the rate of refractory wear in various parts of the furnace. By the time a blast furnace has run its normal life, which may be 8–10 years, considerable changes have taken place in the shape of the interior. Although there is general wear of the lining, the wear is not by any means uniform, so that in places the lining is much thinner than it is in others. Development of blast-furnace linings and design have depended to a large extent on examinations of furnaces after blowing-out, and on laboratory model experiments. The new technique of using radioactive tracers to measure refractory wear during operation of the furnace is yielding useful information on a number of aspects of the problem.

The radioactive isotope used in this work is Cobalt 60, which has a long half-life, gives a strongly penetrative radiation, and is quickly and cheaply produced in the atomic pile. Cobalt pellets have been inserted, at various depths from the surface, into the brickwork of the stack, bosh and tuyere zones, where their presence can be detected by means of a counter. Periodic checking will thus determine when the pellet disappears, i.e. when the refractory has been worn away to a certain depth. Pellets have also been inserted in the carbon bricks of the hearth, in such positions that a counter cannot be taken sufficiently close to check their presence. In this case, when wear on the hearth releases the pellets, they enter the iron and make it slightly radioactive, so that if samples are taken from each cast and checked by a counter, it is possible to determine when the pellet enters the iron. The choice of pellet size is such that the concentration of radioactive material in the iron is far below that likely to constitute a health hazard. In fact, one hundredweight of iron shows only the same effect as it would if the luminous paint from one wrist watch dial were added to it.

In a further application, Cobalt 60 pellets are embedded in the inactive cores of blast furnaces, beyond the combustion annulus, to assist in explorations of the unburnt " dead man " that is supposed to exist in every furnace. The radioactive techniques gain in effectiveness from the extremely sensitive detection equipment in the Normanby laboratories, the scintillation counter in use there having a sensitivity to gamma rays 50 times as great as that of a Geiger counter.

A further aid used by the blast-furnace field team is a high-speed stereoscopic cine technique which is proving of value in an exploration of the combustion zone itself.

Carbon Hearths

Carbon is used for the refractory lining of many blast furnaces in the hearth and bosh zones. Its advantages over the standard 42% alumina fireclay brick are its inertness to chemical attack by iron, slag, alkalis and iron oxide, compared with fireclay, and the reduced tendency of iron to adhere, claimed to result from non-wetting properties. These properties help to prevent breakouts through the hearth walls and reduce the formation of " salamanders " under the hearth bottom.

In the bosh, water-cooled carbon walls provide a satisfactory lining which can be thinner than one built of fireclay bricks. The furnace capacity can thus be increased for the same outside dimensions. In the hearth, however, carbon blocks show a tendency to lift and float on top of the liquid iron. This is because the thermal conductivity of carbon is considerably greater than that of fireclay and iron can penetrate deeper through the joints in the brickwork down to the point at which the metal will " freeze."

The solution to these problems is largely concerned with heat flow, and six blast furnaces now have thermocouples in the brickwork below their hearths to measure temperatures at various levels. In addition, an " electrical analogue " has been built at Normanby, in which electrical resistances can be set to simulate heat conductivity through any particular carbon hearth and thus predict temperatures. A " thermal analogue " has also been built at the Association's Physics Laboratories in London to predict temperatures and rates of heat flow occurring as a furnace hearth slowly heats up. A run of eight hours on the model, for example, corresponds to 2·8 years on an actual furnace and a run of 24 hours represents 8·4 years. The results of the two analogues and of measurements in actual furnaces agree well. Forecasting of the behaviour of proposed designs of hearth seems to be a possible role for the analogues in the future.

It would appear that one solution to the problem is the use of under-hearth cooling by air or water, which may appear an ambitious scheme. It is, however, most certainly practical, and although it has yet to be tried out in this country, it seems likely that the next few years will see a move towards its adoption.

Change of Name

Structural & Mechanical Development Engineers Ltd., 2, Buckingham Avenue, Slough, Bucks, the construction company of the Almin Group, announce that the company name has been changed to : S.M.D. Engineers, Ltd. The company specialises in aluminium construction and prefabrication, marketing the well known ' Alframe ' bungalows, classrooms, hangars, industrial buildings, roofing, etc.

S.M.D. will be remembered for its work in the fabrication of the 365 ft. aluminium ribs for the Dome of Discovery ; the aluminium enclosed telescopic gangways for the ocean terminal, Southampton ; the worlds' first all-aluminium aircraft hangars at London Airport and the 217 ft. clear span aluminium hangar for the Comet jet airliner at Hatfield.

The telegraphic address has also been altered and is now : Alframe Slough.

Mechanical Engineering Research

Progress at East Kilbride Laboratory

IN spite of the slowing down of the building programme, steady progress on research was made at East Kilbride last year. "Mechanical Engineering Research, 1952"* says that there is congestion because of lack of laboratory space, but shows that despite this the Mechanical Engineering Research Laboratory is covering a wide range of research subjects.

Fatigue of Metals

One of the most important subjects on the research programme is the study of the failures of high-speed machinery due to fatigue, that is, to the repeated application of a loading which the component could withstand if it were applied steadily. It is estimated that at least 90% of the failures of high speed machinery are due to this cause. There is much to learn about fatigue. For example, the fundamental physical nature of fatigue is not fully understood and aspects of it are being investigated under contract at Bristol University. The Laboratory itself is following a new line. It has been shown that freshly worked metal surfaces emit charged particles, and as fatigue failure usually starts at the surface, tests are being carried out to see if charged particles are emitted at any stage in fatigue failure.

A type of aircraft pin joint, known to give trouble in service, was among the components tested in the Mechanics and Materials Division. Its very low fatigue failure strength and its poor performance in service were found to be due to fretting corrosion between the pin and the hole in the tongue. Many other failures were investigated for industry, including a large crankshaft, vehicle chassis and engine components, gas cylinders and gas turbine blades.

Large numbers of test pieces are needed for research on fatigue, and a new technique is now being used for producing them. They are profile turned to a tolerance of 0·001 inch on a lathe fitted with a copying attachment and then polished. Before this process was developed several machines and operators were needed continuously. Now only one lathe and a part time operator are required.

Hydraulic Problems

Special work had to be done in the Mechanics of Fluids Division on the design of three special control valves required for the hydraulic machinery laboratory now under construction. Although control valves are used in many industries, there is very little known about their behaviour or the flow patterns inside them. A series of model tests was undertaken to obtain information on which the design of the valves could be based. Details of this work will be published because of the many applications in the water, oil and processing industries.

Research has also begun in this division on the problem of cavitation. The problem first attracted attention towards the end of the nineteenth century when it was found that high-speed ship propellors tended to become corroded and pitted in use to an extent that affected their efficiency. The pitting was found to be caused by air bubbles carried by the water of the propellor stream. The problem is one which now has added importance because of the high propellor speeds used in many craft, and because cavitation is also found to affect the efficiency of water turbines and pumps. Experiments which are being carried out on model scale include the use of high speed photography to study the behaviour of air bubbles from the instant of their appearance until their collapse down stream on the propellor. Cavitation pitting is being investigated under contract at the Mark Laboratories, Keston. The results of the work so far show that there is a relationship between the pitting and corrosion fatigue.

Lubrication

The surface coating of a metal can improve boundary lubrication, and a study has been made of the effect on frictional behaviour of anodized films on aluminium. By anodizing an aluminium alloy and using the correct lubricant, this material, which is normally troublesome, can be made to operate more effectively when rubbing against steel. Experiments with titanium have produced roughly the same results.

In the lubrication of ball and roller bearings, grease is supposed to act as a reservoir for oil, steadily exuding small amounts. To test this theory, and to see whether enough oil reaches the surfaces, roller bearings were made with transparent outer races. When the bearings were rotated the lime-base grease used for the experiments was well churned. After a few revolutions excess grease was squeezed from the bearing and the inner race and cage were revolving in a clear space. Eventually only a minute quantity of grease was left in the path of rolling contact. Although this would normally be enough for lubrication the bearing would finally seize. It is hoped to lay down specifications for better greases as a result of this work.

Condensation Research

In steam condensing plant the cooling surface is covered with a film of water broken by patches of drops. Much higher rates of heat transfer could be obtained if there were no film and all the condensate were in the form of drops. "Dropwise" condensation could mean reduction of the capital cost of new plant and an increase in the capacity of existing plant. Research to try to make this possible has begun at Queen Mary College, London University, under an extra-departmental contract.

Several fatty acids have been found to be effective promoters of dropwise condensation, and further work is being done on the effect of the finish of the surface to which the promoters are applied. A quantitative study of heat transfer with dropwise condensation showed that the overall heat transfer coefficient is double that with filmwise condensation when the cooling water velocity is held constant. To make full use of dropwise condensation higher water velocities than are normal now should be used.

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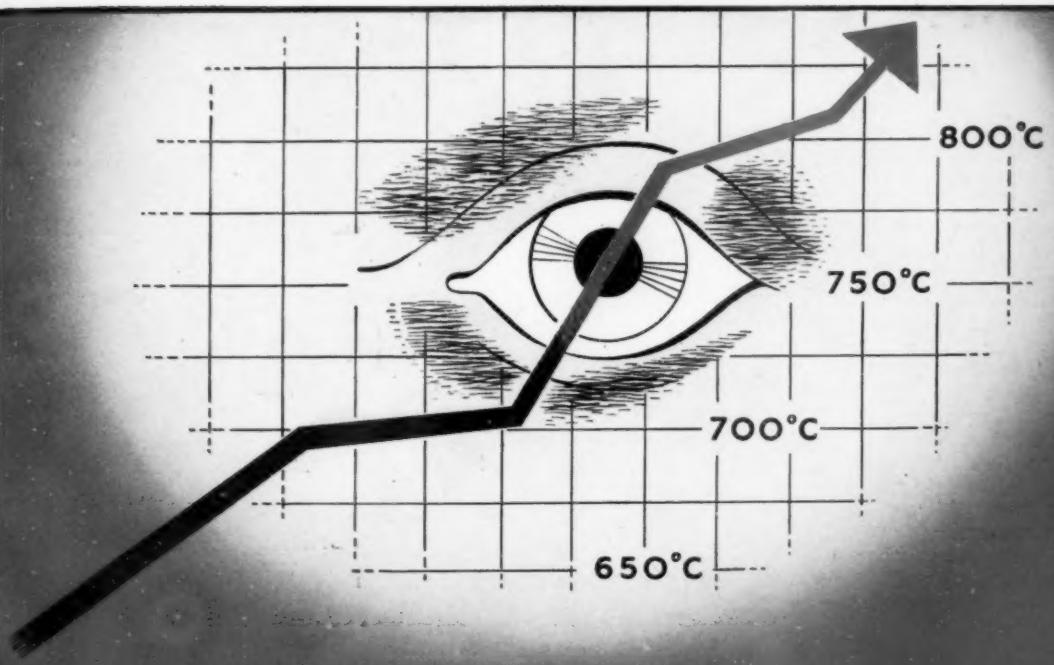

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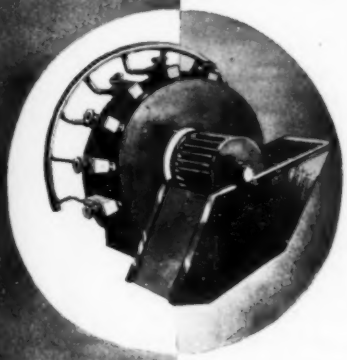

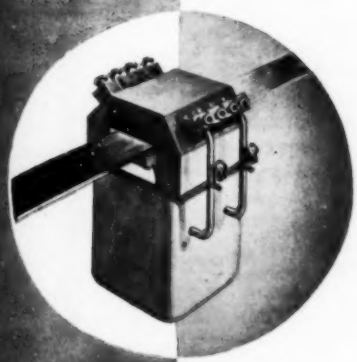

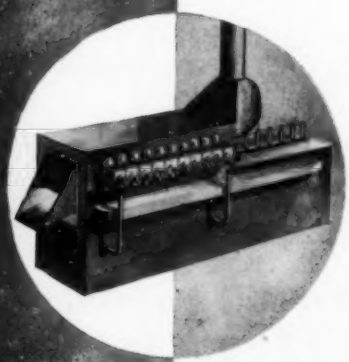

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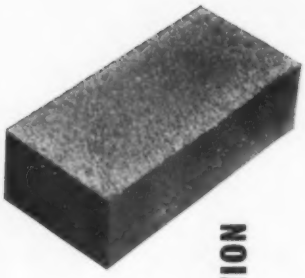

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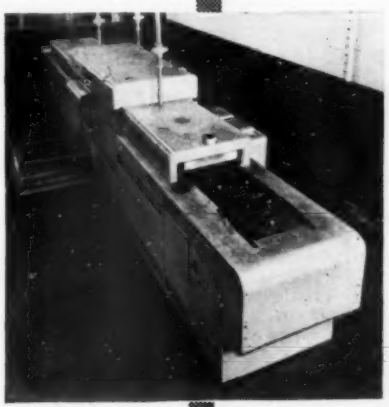

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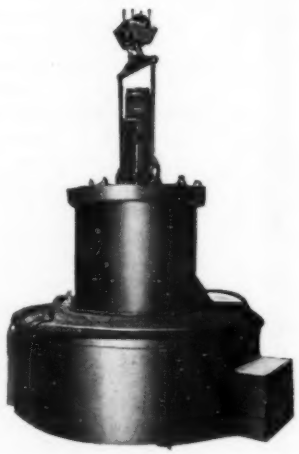

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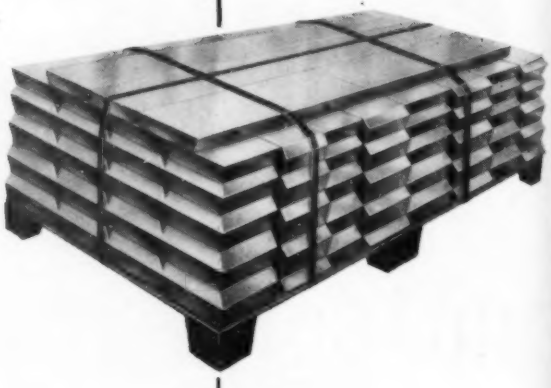

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Phosphate Coatings on Steel Surfaces

By H. A. Holden, M.Sc., A.R.C.S., D.I.C., A.I.M.

The Pyrene Co., Ltd.

It is now almost fifty years since Coslett patented a process for the formation of a phosphate coating on iron articles by prolonged immersion in dilute boiling phosphoric acid solutions. Since that time, considerable developments have taken place and there are now several proprietary solutions available for the production of a range of phosphate coatings. In the present article the author discusses the different types of coating and their application in the fields of corrosion protection, wear prevention and cold-working lubrication.

OF all treatments for iron and steel surfaces, those which can be generally grouped together under the broad classification of "phosphate coating processes" probably enjoy the widest and the most varied application. Not only are they extensively used in protective schemes for preventing the corrosion of steel components ranging in thickness and size from structural steel work to light gauge steel fabrications, such as motor-car bodies, washing machines, refrigerators, etc., but "orthodox" phosphate coatings are now firmly established as lubricant carriers for assisting cold-working operations such as steel wire drawing, tube drawing, deep drawing and cold extrusion. Other additional important applications include the treatment of bearing surfaces to reduce wear and the use of phosphate coatings for electrical insulation purposes.

Protection Against Corrosion

Processes producing a phosphate coating on iron or steel surfaces and designed to assist in the fight against corrosion can be broadly classified into three main groups:

(*a*) those based on solutions consisting essentially of orthophosphoric acid (H_3PO_4);

(*b*) "orthodox" phosphate treatments, i.e. processing solutions containing primary heavy metal (Fe^{++}, Zn^{++} and Mn^{++}) phosphates which produce light grey-black coatings in which the same heavy metal ions predominate; and

(*c*) "light-weight" or "non-coating" processes based on alkali[1] metal or ammonium phosphate solutions which form very thin iron phosphate coatings of low coating weight.

Phosphoric Acid Type Processes

Phosphoric acid pickling for the removal of mill-scale and/or rust is slower and more expensive than hydrochloric or sulphuric acid pickling. It has the great advantage, however, that under certain conditions orthophosphoric acid will react with iron and iron compounds such as mill-scale or rust to produce on the metal surface a film of water-insoluble iron phosphates, which, depending upon its uniformity, adhesion and thickness, can confer some degree of protection against rusting (cf. the susceptibility to rusting of freshly pickled surfaces from sulphuric or hydrochloric acid baths) as well as providing a more satisfactory base for oiling or painting.

Attempts to offset the slow speed and cost of phosphoric acid pickling include the Footner process[2] and the regeneration of the phosphoric acid solutions using ion exchange resins.[3] In the former, the speed of sulphuric acid pickling is coupled with the rust-inhibiting properties of a subsequent phosphoric acid treatment in a solution of controlled iron content. A typical processing sequence for structural steelwork recently installed at a large steel works comprises:

(*a*) immersion in 5% sulphuric acid at 65° C. for 15–25 minutes;

(*b*) two hot water rinses;

(*c*) 3–5 minutes immersion in a solution containing 2% free phosphoric acid (Fe 0·3–0·5%) at 85° C.; and

(*d*) application of a priming coat of paint while metal still warm.

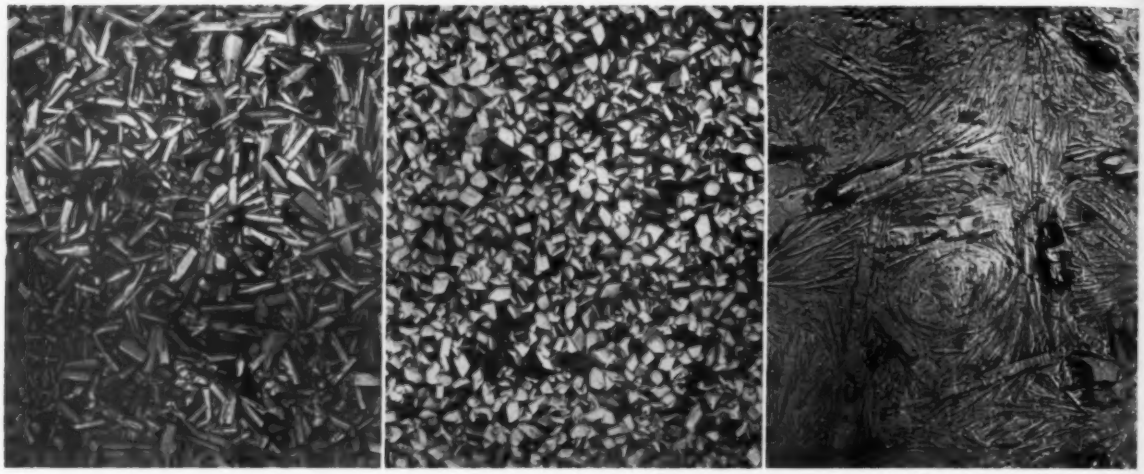
Phosphoric acid based solutions are particularly suitable as rust removers or rust neutralizers, and numerous proprietary products are available for immersion or brush application. Brush treatments or panel washes, usually consist of the acid plus various wetting and surface active agents, and are useful for the *in situ* treatment of large components or structures before painting. As with the immersion processes, however, in order to obtain the best results the surface should be rinsed and dried after treatment and before painting.

An interesting development along somewhat similar lines is the production of phosphoric-acid/solvent-emulsion cleaners which combine the grease- and soil-removing properties of solvent, alkali, or solvent-emulsion cleaners with the rust-removing and passivating properties of phosphoric acid.

Although none of these pickling, rust-removing or cleaning methods is *primarily* designed to form a uniform phosphate coating with definite physical and chemical properties, such as occurs in phosphating proper, phosphate coatings of largely uncontrollable characteristics are produced and these treatments must therefore be mentioned in a survey of this type.

Orthodox Phosphate Treatments

Orthodox phosphate treatment, or phosphating, is essentially a mass-production, industrial, surface pre-treatment method using processes specifically formulated to produce on clean ferrous surfaces uniform, crystalline, tightly-adherent phosphate coatings. These processes are a direct development from the observation made as long ago as 1906 by T. W. Coslett, and patented by him,[4] that a phosphate coating was formed on iron articles by prolonged immersion in dilute boiling phosphoric acid solutions. Treatment times were, however, long (sometimes 3–4 hours), excessive loss of metal frequently



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(a) (b) (c)

Fig. 1.—Types of phosphate coating: (a) thick phosphate coating; (b) iron-manganese phosphate coating as used on bearing surfaces; (c) zinc phosphate coating as used for assisting cold working. × 284

occurred, and the coatings were not reproducible, particularly with regard to their crystal size, uniformity and protective value when used in conjunction with subsequently applied organic finishes.

It cannot be over-emphasised that all phosphate coatings are porous (Fig. 1) and, in consequence, in the bare or as-formed condition they offer little protection against corrosion. In practice, they are invariably used in conjunction with organic finishes such as oils, paints, varnishes, lacquers, etc., for which, due to their crystalline porous nature, they form such an excellent key, and in this way markedly increase their adhesion. In addition, this combination of water-insoluble, tightly-adherent phosphate coating and organic finish ensures greater service life from the finish as compared with its application to a non-phosphated surface (Fig. 2), and if the organic coating is damaged or scratched, revealing the base metal, corrosion remains localised at the damaged area and does not spread under the coating (Fig. 3).

Modern phosphating solutions, prepared by the addition of water to a concentrated chemical in liquid or powder form, consist essentially of primary Fe^{++}, Mn^{++} or Zn^{++} phosphates ($Me(H_2PO_4)_2$)—or mixtures of these—together with some free phosphoric acid, and where short treatment times are required, accelerators such as nitrates, nitrites, chlorates, certain heavy metal ions (Cu^{++}, Ni^{++}) and organic compounds[5] are added. Depending upon the type of coating required, solutions are available with operating temperatures ranging from room temperature (a German war-time development) to just below the boil, and treatment times from a few seconds to 60 minutes or more, and which are suitable for use by immersion or in automatic spray or automatic immersion/spray plants. Plant requirements do not present any difficulty as the solutions can be contained in mild steel, rubber-lined mild steel or acid-resisting brick tanks; no special fume extraction precautions are required, and there are no toxic hazards.

On immersing a clean ferrous surface in an orthodox phosphating solution at the correct operation strength* and temperature, it is immediately attacked by the free phosphoric acid in the solution, causing the primary-phosphate/free-acid equilibrium at the metal/liquid interface to be upset, and precipitating insoluble secondary ($MeHPO_4$) and/or tertiary ($Me_3(PO_4)_2$) phosphates on the metal surface. The type of solution, method of use, and operating conditions determine whether the dissolved iron is largely precipitated as insoluble ferric phosphate sludge or is, to a greater or lesser degree, re-deposited on the work as part of the phosphate coating.

* The strength of phosphating solutions is most commonly expressed in terms of "Pointage," i.e. the number of ml. of $\frac{N}{10}$ NaOH solution required to neutralise 10 ml. of processing solution using phenolphthalein as the indicator. Each ml. of caustic soda solution is called a "point."

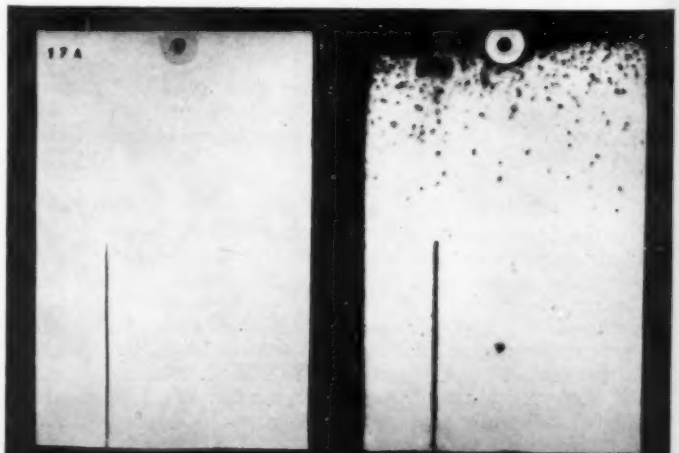


Fig. 2.—Corrosion tests on painted steel sheet after eight months' atmospheric exposure. Both panels had been given one coat of off-white stoving primer, CS 2249: the left-hand panel had been phosphated before painting, whereas the right-hand panel had only been degreased.

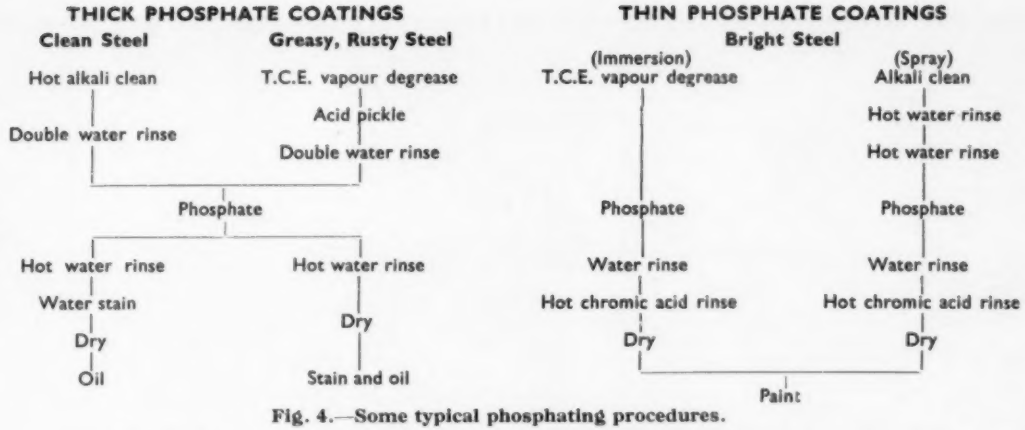


Fig. 4.—Some typical phosphating procedures.

Clearly, coating formation can only occur if (*a*) the solution has unimpeded access to the metal surface, and (*b*) the initial slight pickling reaction occurs. These two factors immediately explain why correct cleaning is such an important part of the orthodox phosphating sequence and why austenitic stainless and many highly alloyed steels cannot be phosphated.

Thick coatings are normally stained and oiled (so called phosphate rust-proofing) whereas the thinner coatings are used almost exclusively as a base for paints. In both cases, however, the processing sequence consists of three distinct stages, all of which are equally important for ensuring the best results.

1. *Cleaning.*—Mill-scale, rust, grease and soil must be removed. Standard methods such as solvent, alkali or emulsion cleaning, acid pickling and sand or shot blasting are satisfactory, although special cleaners for use prior to phosphating have been developed which promote the formation of fine-grained, uniform-textured phosphate coatings. In order to prevent contamination of the processing solution, where alkali cleaning or acid pickling operations precede phosphating, they should be followed by two water rinses.

2. *Phosphating.*—Providing the correct solution strength, operating temperature and treatment time are employed, this operation is perfectly straightforward. Proprietary solutions for such processes as Bonderizing,* Parkerizing,* Granodizing† and Walterising,‡ etc., are so formulated that they require no attention other than replenishment, to compensate for the chemicals consumed during processing, and periodic removal of sludge from the bottom of the tank. With normal care they need never be discarded.

3. *After-Treatment.*—It is always good practice to rinse with water (preferably hot) after phosphating. Although with the unaccelerated phosphoric-acid/primary-metal-phosphate type of solution this is sometimes not considered essential if the processing solution can drain freely from all parts of the surface, all crevice parts should be rinsed to avoid the risk of corrosion.[6] Water rinsing is imperative after the accelerated type of process. Not only does this remove residual phosphating solution, but also traces of loose sludge from the pores of the coating. These might well impair the adhesion of subsequently applied organic films.

In addition, a further quick (30 seconds) rinse, preferably hot (160°/170° F.), containing a low concentration of chromic acid (0·1–0·5%)[7] should be used if a final paint coating is to be applied, as it has been established that this increases the corrosion protective value of the system. The coatings should then be thoroughly dried and the finishing system applied *as soon as possible* so that full advantage is taken of the chemically clean, absorptive base provided for its acceptance.

Typical phosphating sequences are shown in Fig. 4 which clearly illustrates significant points considered above.

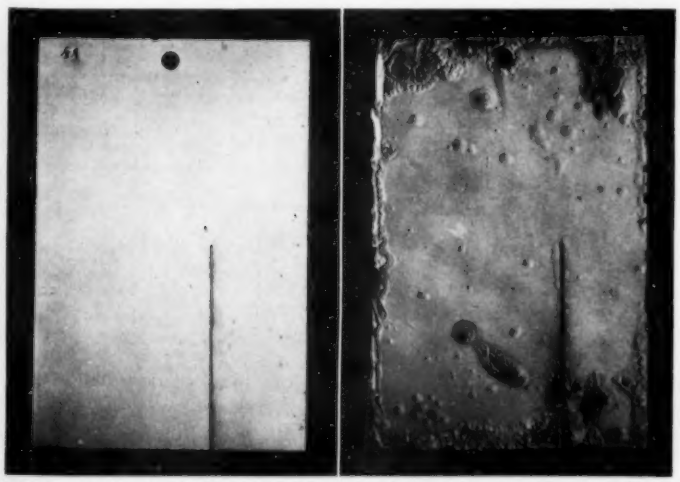


Fig. 3.—Corrosion tests on painted steel sheet after 450 hours' sea-water immersion. Both panels had been given two coats of refrigerator finish: the left-hand panel had been phosphated before painting, whereas the right-hand panel had only been degreased. Note the failure at the scratch.

Thick Coatings

A thick phosphate coating impregnated with oil or a suitable finish—almost invariably black—is a simple and highly effective method of protecting nuts, bolts, screws, washers, nails, rivets, small castings, ordnance, fire-arms, tools, camera parts, etc. Not only is a high degree of corrosion

* The Pyrene Co., Ltd.
† Imperial Chemical Industries, Ltd. (Paints Division).
‡ Walterisation, Ltd.

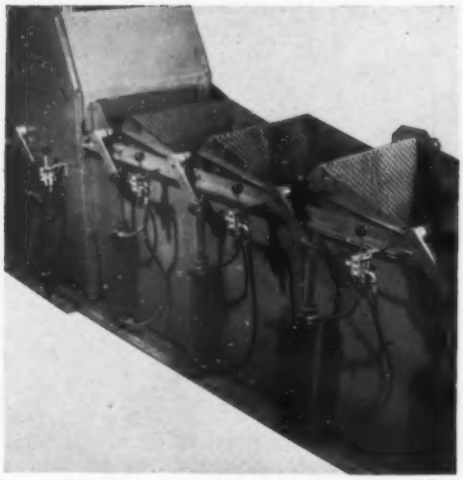


Fig. 5a.—Close-up of pneumatically operated "T.B." (tipping basket) machine showing principle of operation.

Courtesy of Vauxhall Motors, Ltd.

Fig. 5b.—Fully automatic "T.B." machine for Parkerizing chassis details like nuts and bolts.

protection afforded, but with these processes little change in dimensions of the components is involved, the physical properties of the metal remain substantially unaltered, and with certain solutions mixed iron, steel, brass and bronze assemblies can be treated.

When the highest protective qualities are required, unaccelerated solutions, such as the original Parkerizing "A" (iron-manganese phosphate) process are still employed. This solution operated at 210° F. produces in 45–60 minutes coating weights of $\lesssim 1{\cdot}5$ g./sq. ft., the completion of the treatment being denoted by the cessation of gassing. To meet the demands of modern production requirements, however, new Parkerizing solutions have been developed which necessitate only 5–10 minutes treatment times at temperatures of 170°–185° F. The rotary barrel method of processing is adequate for phosphating relatively small quantities of small components, the rotation ensuring that the solution comes into contact with every part of the metal surface. For larger productions, the "T.B." (Tipping Basket) type rust-proofing machine[8] is more suitable as the small parts can be processed through the complete cycle of operations, i.e. cleaning, phosphating, rinsing, drying and impregnating. The tipping action again ensures that the entire surface is treated. Hand operated and pneumatically operated machines are available (Fig. 5).

Thin Coatings

The widespread present-day uses of light gauge steel, particularly in the building industry,[9] were to some extent made possible by the greatly improved resistance to corrosive attack afforded by an orthodox phosphate treatment of the material before painting. Light to darkish-grey coatings are produced in a few seconds to 10 minutes or so, depending upon the particular process employed and the physical characteristics of the coating required. The solutions are based on zinc phosphate, almost without exception, and operate within specific narrow temperature limits within the overall range from room temperature to 185° F.

Although solutions are available for application by brush or by means of an ordinary paint spray gun, and although there are many small hand-operated immersion plants throughout the country, by far the largest surface area of steel phosphated is that passing through large automatic plants installed for treating sheet metal, motor car bodies, bicycles, refrigerators, washing machines, etc., before painting.

On automatic *immersion* plants the suitably jigged components are usually suspended from a mono-rail conveyor or flight bar and then carried through a sequence of hot alkali cleaning, double water rinsing, phosphating, hot water rinsing, chromic acid rinsing, and oven drying stages. As a general rule, coating weights are 250–750 mg./sq. ft. and the phosphate treatment times 3–10 minutes or so.

Spray phosphating is the ideal conveyorized mass production surface pretreatment method where the shape of the article is such that all parts of the surface can be reached by the *sprayed* solution. Not only does this procedure enable the processing time to be reduced to 30–60 seconds, but thinner, smoother, more glassy-looking phosphate coatings are produced at less chemical cost than by immersion. The coating weight range is usually 150–250 mg./sq. ft. The work is suspended from a mono-rail conveyor and passes through various processing zones, each of which contains a number of stand-pipes fitted with jets through which the appropriate solution is sprayed. After spraying, the solution returns to a tank under the zone and is then pumped up into the stand pipes again.

A typical six-stage Spra-Bonderizing plant comprising spray alkali cleaning, two spray hot water rinses, spray phosphating, spray hot water rinse, and spray chromic acid rinse is shown in Fig. 6. Some five-stage machines operate with emulsion cleaning and one spray water rinse before phosphating.

A special technique was developed to deal with the protection problems raised by the modern unit construction in motor car body design, where the body and chassis are one; the latter consisting of light-gauge steel box sections. The body is mounted on a spit which causes it to rotate on its horizontal axis at the same time as it is carried through a normal six-stage processing sequence. At each stage, the rotating body receives a combination of spraying and immersion, thus ensuring

that the insides of the box sections are processed. After drying, the Roto-Bonderized body, still rotating, is immersed in a tank of priming paint and then stoved.

Orthodox phosphating solutions are also available for treating aluminium, cadmium and zinc, and the combination of a thin electrodeposited zinc coating (0·00005–0·0001 in.) followed by phosphating confers a higher degree of corrosion protection than would be obtained if the paint were applied to the zinc or the phosphate coating alone.

Light-Weight Coatings

During the past two or three years, the so-called non-coating or light-weight coating types of process such as Bonderite 55 and Granodine 400, etc., have been introduced. Coating weights of 50–100 mg./sq. ft. are produced by immersion or spraying, and the treatments are always used as a base for paint. Although present experience seems to show that when the highest protection is required, as for example on motor car bodies, the orthodox zinc phosphate coatings should be employed, light-weight coatings are finding a definite place in the phosphating field. The solutions have no rust-removing properties and can only be used on bright steel surfaces. They possess some detergent qualities and can be used as combined cleaning/coating solutions. A typical four-stage spray system would include :

(*a*) 1st zone : Spra-Bonderite 55 } dual purpose
(*b*) 2nd zone : Spra-Bonderite 55 } cleaning/coating
(*c*) 3rd zone : water rinse ; and
(*d*) 4th zone : chromic acid rinse (hot).

Where this type of process is to be used by immersion, particular care must be paid to the cleaning, and in some cases it may be necessary to include alkali or emulsion cleaning followed by water rinsing before phosphate treatment. Plant maintainance costs are considerably lower than with the orthodox processes, as the solutions work almost free of sludge.

Courtesy of Ford Motor Co., Ltd.

Fig. 7.—The Parco-Lubrizing of camshafts for "Consul" and "Zephyr" engines at the Ford Motor Co., Ltd., Dagenham.

Reduction of Wear

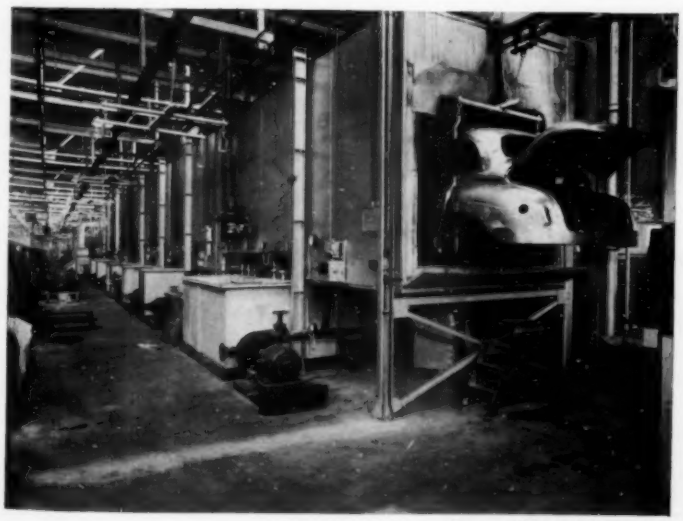
An important use for phosphating, somewhat intermediate between the two major applications of corrosion protection and lubrication in the cold working of iron and steel, is as a means of preventing the wear of parts subjected to sliding friction. Iron-manganese coatings have proved to be the most satisfactory[10] and are, of course, always used in conjunction with a lubricant such as oil, grease or molybdenum disulphide.[11] As this type of treatment is usually applied to precision parts, a special process, Parco-Lubrite, has been developed which gives reproducible coatings of uniform crystal size, thus enabling accurate tolerance requirements to be maintained.

The coating prevents metal-to-metal contact between bearing surfaces during the initial running-in period, so that faster running-in can be effected without scuffing or pick-up. In addition, due to the porous nature of the coating, the lubricant is retained where it is most needed.

Many well known motor car companies have now adopted this treatment for engine transmission or differential components ; typical application including piston rings, cylinder liners, pistons, crankshafts, differential gears, bearing races, etc. (Fig. 7). This treatment has also proved effective for reducing fretting corrosion.

Phosphating for Cold Working

Although in this country the use of zinc phosphate coatings to assist the cold working of iron and steel is a comparatively recent innovation, it is now almost 20 years since this particular property of phosphate coatings was first discovered. In 1934, Fritz Singer was carrying out some deep drawing



Courtesy of The Daimler Co., Ltd.

Fig. 6.—A new 6-stage Spra-Bonderizing machine recently installed by The Daimler Co., Ltd., for The treatment of steel bodies for Lanchester and Daimler cars.

Courtesy of Reynolds Tube Co., Ltd.

Fig. 8.—A load of tubes about to be Bonderized as an aid to drawing.

experiments in the workshops of Neumeyer A.G. Nuremberg, in connection with the manufacture of steel shell cases, and found that heavier reductions in wall thickness could be performed if the steel were phosphated prior to lubrication and drawing. As a result, he filed his well-known patent[12] in which he states "the difficulties and disadvantages encountered (heretofore) as a result of metal-to-tool contact in mechanically working metal articles by drawing, rolling and similar operations, can be avoided or overcome by providing the surface of the article with a thin, crystalline, coherent coating of a metallic oxide or salt (phosphate), the crystals of which are in a heterogeneous crystalline union with the metal base and tightly grown together with the latter, and thereafter subjecting the coated articles to the working operation."

In the following year it was shown that, by the use of a zinc-phosphate/lubricant system, steel could be cold extruded, and the scene was set for a virtual revolution in the German cold working industry. The use of the phosphate/lubricant system was extended to other operations such as tube drawing and wire drawing, so that during World War II more than 600 German firms were using the process, which became generally known as "Bonder Drawing." In the peak year, 1943/44, nearly 16,000 tons of this particular phosphating chemical were used in Germany.

It is not yet completely understood why the zinc-phosphate/lubricant system is so effective in assisting cold working, but two factors which are obviously of great importance in this respect are (*a*) the flow of the phosphate coating with the metal on working, and (*b*) the reaction between the lubricant and the coating resulting in zinc soap formation.

When a uniform, tightly-adherent, crystalline zinc phosphate coating is formed on a surface, correctly lubricated, and cold working then carried out, part of the coating is removed. The remainder flows with the metal, becoming transformed into a smooth, grey, glassy layer which acts as a continuous parting layer between the surface of the work and the die, thus reducing friction, pick-up, galling, etc. On subsequent drawing this film becomes progressively thinner until finally it has all been removed. It must then be renewed by phosphating again.

It has also been suggested that, due to their water insolubility and temperature stability, phosphate coatings may be considered as fixed inorganic fillers for the lubricants. Although this may to some extent be true, the reaction which occurs between solutions of polar materials, such as soaps, vegetable oils, animal fats, etc., and a zinc phosphate treated surface is much greater in importance. It has been shown[13, 14] that this reaction results in the precipitation of insoluble zinc soaps which become interlocked with the coating. These films are formed by a mixture of both adsorption and chemical reaction and, in consequence, are tightly anchored to the phosphate coating, which is itself securely keyed to the underlying metal.

Lubrication before tube drawing and cold extrusion is normally carried out by immersing the phosphated steel in the lubricant, thus ensuring the maximum opportunity for the reaction to proceed. In order to obtain the most satisfactory conditions, particular attention has been paid to lubricant composition, concentration, *p*H, temperature, and immersion time. In fact, in addition to the production of special processing solutions designed to form the satisfactory zinc phosphate coatings for cold working, special lubricants (Bonderlubes) have now been developed for use on Bonderized surfaces.

Much still remains to be learned about the reasons for the effectiveness of this treatment, and this is yet another instance where established industrial practice is ahead of the underlying scientific theory.

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In the field of cold drawing, phosphating for tube drawing has undoubtedly received the most publicity. This is probably because (*a*) it was the first industry to which the process was applied on any large scale, and (*b*) the benefits produced were very marked and the economic advantages were quickly appreciated.

The process is now generally used, both in this country and abroad, for multi-pass drawing, and in the past few years the bulk of this type of seamless steel tubing produced in this country has been phosphated (Fig. 8). It is also used in the United States and Germany for assisting the drawing and sinking of welded steel tubing. A typical sequence of operations is that the hot-formed hollows are pickled as in normal practice, given two water rinses to prevent acid carry over into the phosphating solution, phosphated for 3–10 minutes, depending upon the amount of cold working to be performed, hot water rinsed, and then lubricated by immersion in the hot lubricating solution.

Phosphating has, therefore, replaced the conventional "sull coating" or "rusting" operation which, when heavy passes were involved, frequently took up to two hours. Instead of having to anneal, pickle, and re-coat after each draw, as previously, Bonderizing has enabled up to five consecutive draws to be carried out with only a simple re-lubrication between each pass. In normal practice, the majority of seamless tubes drawn on a phosphate coating require only two or three consecutive

passes, but the economic advantages of being able to eliminate one or more heat treatments are immediately obvious. In addition, this phosphate/lubricant system, which is applicable to plug and mandrel drawing, enables faster drawing speeds to be used and heavier draws to be employed, produces a superior finish on the drawn article, and overcomes pick-up trouble.

Wire Drawing

Another industry which has markedly benefited from the use of a zinc phosphate drawing coat is that of steel wire drawing. Although this particular development was only introduced into this country some five or six years ago, a large number of the firms drawing steel wire are now using this surface treatment method for assisting both wet and dry drawing.

In dry drawing, the phosphate coating, as with tube drawing, replaces the conventional "sull coating" by producing a consistent, uniform, tightly-adherent crystalline coating, independent of the prevailing atmospheric conditions or the whims of the cleaning yard operator. A typical batch cleaning procedure includes hot sulphuric or cold hydrochloric acid pickle, pressure water spray, immersion cold water rinse, phosphate 3–10 minutes, cold water rinse, hot lime or borax dip and oven dry (Fig. 9).

Courtesy of Frederick Smith & Co. (Wire Manufacturing) Ltd.

Fig. 9.—A large plant for the Bonderizing of steel wire prior to dry or wet drawing.

In addition to the reduced treatment time compared with "sull" coating, and the reproducibility of the drawing coat, phosphating results in fewer stoppages and material breakages, increased die life, improved surface condition of the drawn wire, better corrosion resistance of the drawn wire during storage, and faster drawing speeds. In connection with the latter, Holloway[15] has reported finishing speeds of 2,000 ft./min., coupled with excellent spindle efficiencies, when drawing 0·73% C Bonderized wire from 9 S.W.G. to 18 S.W.G. (total reduction in area of 89%).

A phosphate coating is equally beneficial for assisting the wet drawing of both iron and steel wire, particularly where the drawing of fine wire at high finishing speeds is involved. In this case, the zinc phosphate coating replaces the customary copper lacquer coating. The higher finishing speeds associated with the introduction of the phosphate coating have not been coupled with any reduction in machine efficiencies; in fact, efficiencies have increased. In addition, the surface of the drawn wire is of excellent quality, has a most attractive appearance, and can be readily tinned or galvanized using standard practice.

Phosphate coatings are also beneficial in assisting the drawing of sectional or shaped wire[16], enabling heavier reductions to be effected, and, in some cases, interanneals to be eliminated and power requirements reduced.

Cold Extrusion

Although the cold extrusion of steel was first successfully carried out in 1935, and widely used in Germany during the war, the first American Government investigation was not started until 1946 and it was not until May, 1953, that the first attempt was made in this country to disseminate knowledge on this most important subject.[17] Naturally, German work was largely devoted to the manufacture of steel cartridge cases and shell, and the American work has also been largely concentrated on ordnance projects.

The particular advantages of cold extrusion include savings in steel (e.g. it is estimated that the production of the 105 mm. shell by this technique would effect a saving of approximately 40% in the steel used as compared with conventional methods[18]); a saving in machining operations; the possibility of using low carbon-manganese steel from which the necessary physical properties could be produced by the extrusion operation; and superior surface finish.

Although opinions differ on the most suitable types of press, on the composition of the steels to be extruded and on the properties of the die steels, there is general agreement that a zinc phosphate treatment in conjunction with the correct lubricant must be used prior to extrusion. In fact, it has been authoritively stated that without this method of surface preparation, the cold extrusion of steel (where heavy reductions are involved) would not be possible.[19] Under the exacting conditions which exist during cold extrusion, it is essential that both the phosphate coating and the lubricant system are correct and a coating weight of at least 1 g./sq. ft. is usually required for heavy extrusion work.

Bearing in mind the zinc soap formation, which is believed to play such an important part in the phosphate/lubricant system, special lubricants have been developed for assisting cold extrusion. The Bonderized components are usually immersed for several minutes in the hot lubricant solution, although for some light drawing work the lubricant may be sprayed on to the phosphated surface. Before extrusion it is essential that the lubricant film is completely dry, or otherwise excessive press loads may be built up and drawability reduced. Many heavy gauge articles will dry satisfactorily under their own heat, but others may require drying in an oven, or by means of a fan blowing hot air over them.

Continued on page 90

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Recent Developments in the Fusion Welding of Iron and Steel

By J. W. Shedden, B.Sc., F.I.M., A.M.Inst.W. and
W. I. Pumphrey, M.Sc., Ph.D.
Murex Welding Processes, Ltd.

Considerable advances have been made in the fusion welding of iron and steel in recent years and in this article the authors discuss such aspects as electrode coatings, low hydrogen electrodes, stainless steel deposits, the welding of cast irons by the metal-arc process, automatic inert-gas-shielded-arc welding and gas welding.

THE application of welding as a constructional process is increasing every year, as is evidenced by the curve, plotted in Fig. 1, showing the yearly consumption of metal-arc welding electrodes since 1938.[1] Fig. 1 also shows the number of new arc welding plants installed annually in this country during the last 15 years. If the peak output during the war years is ignored, a steady upward trend is revealed by these returns, which is indicative of the confidence placed in fusion welding processes. During the immediate post war years there has been a growing appreciation of the technical aspects of metal-arc welding and it is proposed, in this article, to describe some of the more recent developments which have taken place in the arc welding of iron and steel.

There has also been expansion in the use of the gas welding and automatic inert-gas-shielded-arc welding processes, but statistics are not so readily available in these cases to indicate the progress made. Some attempt will be made, however, to describe the more outstanding developments in these processes in recent years.

The increasing use of alloy steels, in both cast and wrought forms, and the growing tendency to fabricate large complex structures by welding together a number of smaller castings or forgings, has made demands on the welding industry which have been met satisfactorily, and some of the impressive welded fabrications recently completed, and illustrated here, may serve as examples of the more specialised developments in the fusion welding of iron and steel.

Metal-Arc Electrode Coatings

The functions of the various constituents used in modern electrode coatings are becoming better understood as is evident from the fact that a classification system for these coatings has recently been embodied in a British Standard Specification.[2] A brief description of some of the more popular types of flux coating may serve as a basis for this account of the recent developments in metal-arc welding. Electrodes identified as Class 2 in the British Standard Specification referred to above, for example, which have coverings with a high titania content and produce a fairly viscous slag, are perhaps the most widely used of all metal-arc electrodes in this country, and are particularly easy to use for welding in the downhand or horizontal-vertical positions: the slag can be detached readily and the weld has a smooth appearance. Another popular type of electrode is designated as Class 3, and although this type also has a covering containing an appreciable amount of titania it produces a fluid slag. The presence

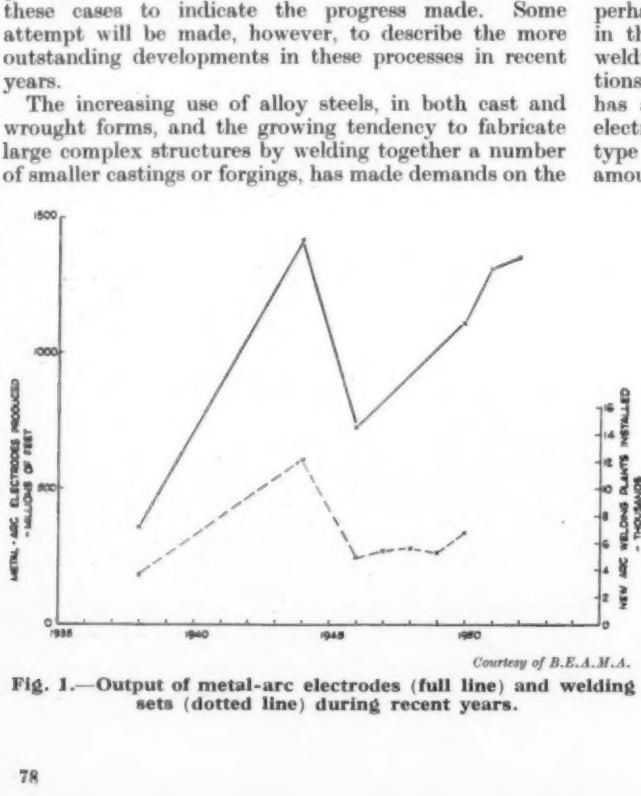


Fig. 1.—Output of metal-arc electrodes (full line) and welding sets (dotted line) during recent years.

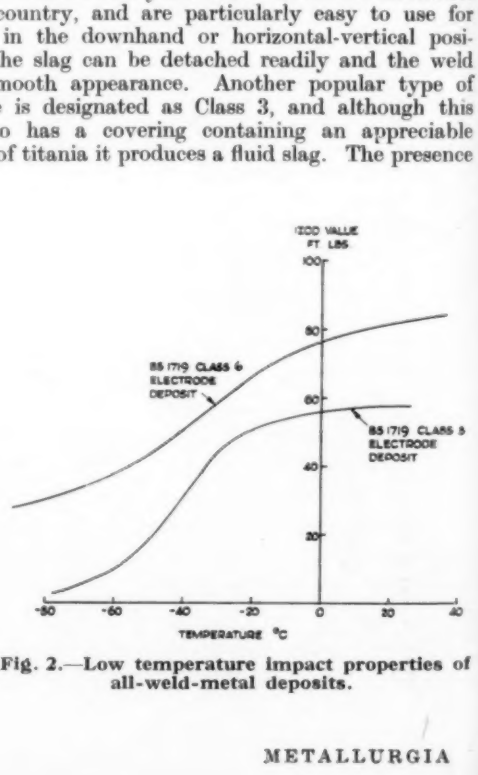


Fig. 2.—Low temperature impact properties of all-weld-metal deposits.

Courtesy of Whessoe, Ltd.

Fig. 3.—Welded storage tanks for the petroleum industry.

of certain basic materials in the coating is responsible for the increase in slag fluidity, and this permits of welding in the vertical and overhead positions. These electrodes can also be used for welding in the downhand position, in which case a reasonable degree of radiographic soundness can be obtained in the weld deposits.

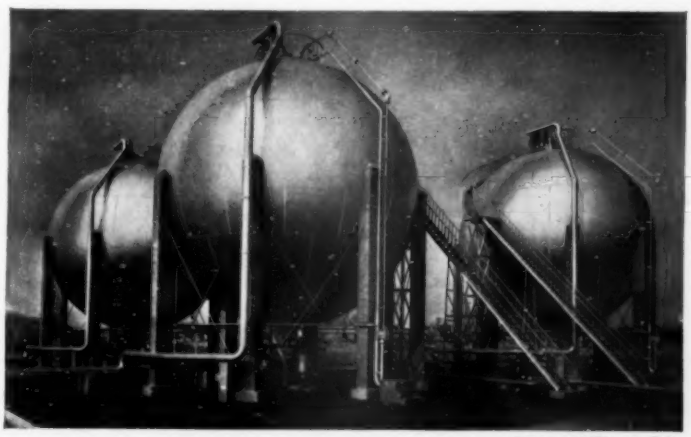
With Class 4 type electrodes, the coatings produce an inflated slag having a high content of oxides and/or silicates of iron and manganese. Deposits from these electrodes give the highest degree of radiographic soundness, and deep-groove butt joints on large pressure vessels are normally welded with this type of electrode. Finally, there are the electrodes with the Class 6 type of covering which have a high content of calcium carbonate and fluoride. Electrodes with this type of coating produce a fully basic slag, and give a weld deposit low in total gas content: they are sometimes referred to as "low hydrogen" electrodes. The weld metal possesses enhanced mechanical properties—in particular, a high impact figure at low temperatures (see Fig. 2). Other standard types of coating, as well as special coatings which are used for deep penetration and high-deposition-rate welding operations, are described in B.S.S. 1719[2] but a detailed consideration of all these types is outside the scope of this article.

Some further indication of the relative merits of the types of electrode coating described above is afforded by reference to the applications of each type in the welding industry. In this connection a rough distinction may be drawn between the larger site-welding work, in which mild steel material is mainly used, and the more specialised shop-fabrication work, where low-alloy steel is often used, and subsequent heat treatment of the finished component is often carried out.

Site Welding

The oil refinery construction programme which is being carried out in this country is proving a major achievement for the welding industry. As many of the storage vessels and refinery columns are too large for shop manufacture and transport to site in one piece, a considerable amount of site welding is necessary. Electrodes with Class 2 and Class 3 coatings are used for the circumferential and vertical seams, respectively, of the massive storage tanks seen in Fig. 3. For the welded Horton spheres (Fig. 4) deposition in the semi-overhead position is also required. An increasing amount of radiographic examination is being applied to the welded seams in these structures and quite satisfactory results are being obtained with the Class 3 type of electrode. Mild steel plate is used normally for these vessels, but some measure of preheating prior to welding is recommended for the thicker plates: this can be effected conveniently by means of portable gas burners.

There has been some trend towards the use of low-alloy steels for this outdoor construction work, and typical compositions of a number of such steels are given in Table I. The mechanical properties are also given and, for comparison purposes, the yield and ultimate stress values obtainable with all-weld-metal deposits from Class 2, Class 3 and Class 6 electrodes have been included. The improved yield stress values of the low-alloy steels allow an appeciable saving in total weight where structural designs are made on a strength basis. The high yield stress values reported for the weld metal should be noted, as the use of such weld



Courtesy of Whessoe, Ltd.

Fig. 4.—Welded storage spheres.

Courtesy of Stewarts & Lloyds, Ltd.

Fig. 5.—Walking dragline in operation at Corby.

metal enables the full advantages of welded construction methods to be realised when low-alloy steels are used.

Applications involving the welding of low-alloy steels include the construction of motor canal boats[3] where the steel plating has been made in 37/43-ton U.T.S. material. The reduced weight of steel needed has been found to offset the increased price of the alloy steel, while the change from a riveted mild steel construction to a welded alloy steel vessel has resulted in a 10% increase in carrying capacity. Some reference should also be made here to the large walking dragline now in operation at Corby, the successful construction of which was a result of the use of low-alloy steel in a welded structure. The tubular jib members were made in the chromium-molybdenum type of steel[4], the composition of which is given in Table I. Local preheating to approximately 150° C. was carried out prior to the site welding operations, and the welds were protected during cooling with asbestos blankets. Subsequent heat treatment was not considered necessary when these precautions were observed. The dragline is shown in Fig. 5.

The development of low alloy steels with improved weldability has been intensified during recent years[6], and when such steels become more readily available still greater advances will be made in the building of massive structures by welding.

Shop Fabrication

The construction of large pressure vessels of the type shown in Fig. 6 necessitates the highest degree of technical control at all stages of the welding procedure[6]. Furnaces large enough to accommodate the whole structure must be available for initial preheating and subsequent stress relieving treatments. The deep-groove joints are welded using the Class 4 type of electrode, and rotation of the vessel is arranged so that welding in the downhand position can be applied for the

TABLE I.—MECHANICAL PROPERTIES OF MILD AND LOW ALLOY STEELS FOR WELDING PURPOSES.

Description	Chemical Composition—%				Yield Stress tons/sq. in.	Ultimate Tensile Stress tons/sq. in.
	C	Mn	Cr	Mo		
Mild Steel	0·23 max.	0·3/0·8	—	—	15·25 min.	28/32
High Tensile Structural Steel	0·23 max.	1·8 max.	—	—	23 min.	37/43
High Tensile Structural Steel	0·23 max.	0·8 max.	0·8 max.	—	23 min.	37/43
Chromium-Molybdenum Alloy Steel	0·20/0·25	0·6/0·7	0·6/0·7	0·2/0·3	21 min.	33 min.
All Weld Deposits:						
Class 2 Electrode	0·06	0·65	—	—	30	32/38
Class 3 Electrode	0·07	0·35	—	—	28	30/35
Class 6 Electrode	0·06	0·70	—	—	30	33/35

circumferential seams. In many cases, the longitudinal seams are made using one of the automatic welding processes. It is usual for 100% radiographic examination to be specified on the welded seams in this kind of vessel.

The shop construction of components in the medium-tensile steels has increased during recent years. These materials are often more highly alloyed than those shown in Table I, and greater precautions during their fabrication are needed. The main difficulty in the welding of such steels is due to the hardening of the parent material, because of the heating and cooling cycle to which it is subjected during welding, and the resultant formation of underbead cracks of the form shown in Fig. 7. The degree of hardness in the heat affected zone immediately adjacent to the weld deposit depends primarily on the composition of the steel. The effect of the various alloying elements on thermal hardening has been assessed[7], and by the use of divisors for the percentage of each element present in the steel it is possible to calculate a carbon equivalent for any given alloy steel as may be seen in Table II. Experience has shown that for a steel with a given carbon equivalent it is possible to recommend the type of electrode to be used and the degree of preheating necessary if underbead cracking is to be avoided. Some degree of hardening beneath the weld deposit will still occur, however, even with the use of a selected electrode and welding procedure, and tempering after the welding operation at 550–600°C. is necessary, especially with structures liable to be subjected to alternating stresses, or in cases where machining operations have to be completed after welding.

Low-Hydrogen Electrodes

The effect of hydrogen on the occurrence of the underbead type of cracking has been studied extensively. During any fusion welding operation, the material in the vicinity of the weld is heated to a temperature at which it is wholly austenitic, and while in this condition it is capable of dissolving hydrogen which diffuses into it

TABLE II.—RECOMMENDED ELECTRODES FOR MILD AND LOW ALLOY STEELS.

Steel En No. (B.S. 970)	Chemical Composition—%					Carbon Equivalent%	Class of Electrode B.S. 1719	Preheating Treatment
	C	Mn	Ni	Cr	Mo			
3	0·25 max.	1·0 max.	—	—	—	0·33	Class 2	None
							Class 3	None
6	0·40 max.	0·5/0·9	—	—	—	0·45	Class 3	100° C.
							Class 6	None
12	0·30/0·45	1·5 max.	0·6/1·0	—	—	0·63	Class 6	150° C.
							Austenitic	None
25	0·27/0·35	0·5/0·7	2·3/2·8	0·5/0·8	0·4/0·7	0·85	Austenitic	100° C.

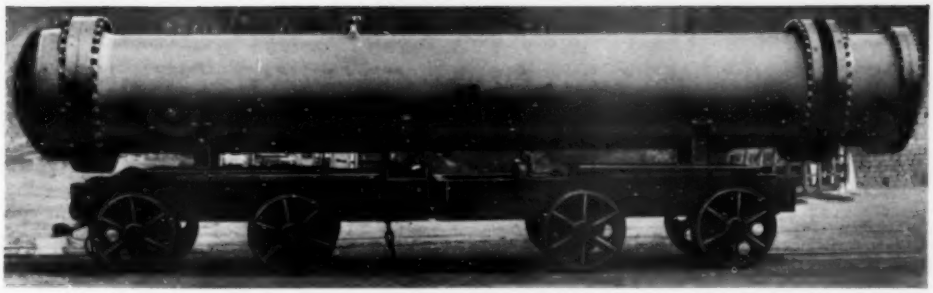


Fig. 6.–Large welded heat exchanger.

from the weld metal and from the surrounding arc atmosphere. If the steel contains the required proportion of alloying elements, transformation of the austenitic structure to martensite can occur during cooling, and, in the absence of preheating, a partially or wholly martensitic structure may be developed. This transformation, which takes place at a comparatively low temperature—around 300° C.—is accompanied by a considerable volume expansion, and if the material is unable to accommodate the resultant stresses, cracking can occur. This condition is considerably aggravated if hydrogen is present, due to the fact that hydrogen is less soluble in ferrite (or martensite) than it is in austenite. Any hydrogen which is dissolved in the austenite is forced out of solution at the transformation temperature during cooling and tends to accumulate, under pressure, at any discontinuity within the internal structure of the steel. The resulting internal stresses, coupled with the transformation stresses, greatly aggravate any tendency for hard zone cracking to occur.

The transformation stresses may be minimised by preheating, which causes the welded structure to cool down sufficiently slowly for the austenitic areas to transform to pearlite. Adequate preheating of large structures may be difficult to effect, however, and in such cases the use of the low-hydrogen (Class 6) type of electrode is of great benefit. With the more highly alloyed steels, the Class 6 type of electrode may still be used in conjunction with some measure of preheating, or, alternatively, the fully austenitic type of electrode may be used. In the latter case, the hydrogen which is ejected from the austenitic areas of the plate material during cooling can diffuse to and be accommodated in the weld metal. The austenitic electrodes are expensive, however, and the tensile properties of the final weld may not be adequate for design purposes.

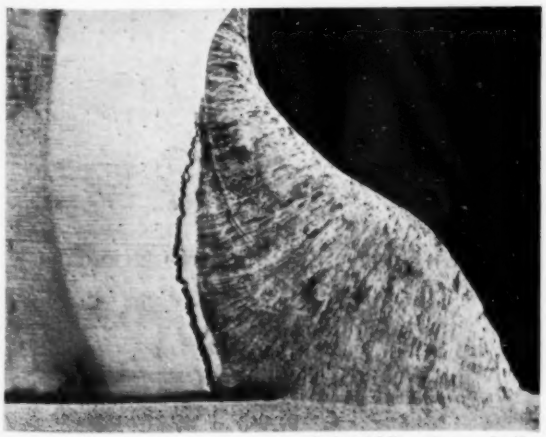


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Fig. 7.—Underbead crack in hardened zone formed during fillet welding of alloy steel plate material. ×5

Experimental work[8] has been carried out recently to determine the maximum rates of cooling in the heat affected zone which may be permitted if cracking is to be avoided in a welded structure. These experiments were repeated using electrodes of the normal and the low-hydrogen categories, and for one particular low-alloy parent plate material the following results were obtained.

Type of Electrode Coating Used for the Welding	*Maximum Cooling Rate for the Avoidance of Cracking*
Class 2	6° C./sec.
Class 3	8° C./sec.
Class 6	11° C./sec.

The greater degree of safety possible with Class 6 electrodes is very evident from the above figures. These electrodes are low in available hydrogen because their coatings contain quantities of minerals which evolve gases other than hydrogen. Such gases serve not only to shield the weld metal from hydrogen pick-up during deposition, but also to dilute any moisture vapour formed from slight traces of residual moisture which may be present in the coating.

Preheating Treatments

The importance of adequate and controlled preheating will be clear from the foregoing remarks, and some brief reference may be made to the methods employed for such treatments. When shop heat treatment furnaces are available, preheating of the whole assembly in this type of furnace is no doubt the most suitable method. Local preheating may have to be resorted to, however, in some cases, and this can be carried out with gas torches or various forms of electrical heating. Electrical resistance strip heaters[9] are popular where a continuous application of the preheat is advisable, while low-frequency induction heating[10], as shown in Fig. 8, can be applied, using a current supply from the ordinary type of welding transformer. In some cases it is possible to carry out the welding operation while the heating current is still applied, but in other cases the arc action of the electrode may be affected adversely.

Automatic Welding Processes

The longitudinal seams of large cylindrical vessels and deck welds in the shipbuilding industry are two major uses for automatic welding processes. The submerged arc process, where the powdered flux is fed into the prepared joint ahead of the welding arc, and the continuous wire-wound, flux-coated electrode process find many applications in the heavy engineering industries to-day.

Fig. 8.—Induction " coil " for preheating of high carbon steel shaft.

The atomic hydrogen welding process is perhaps more applicable to the automatic welding of lighter components. With slow cooling, much of the hydrogen which has become absorbed in the molten weld metal is able to escape and the final deposit should be no higher in hydrogen than a normal metal-arc weld deposit. This hydrogen content may not be low enough, however, for the satisfactory welding of the low alloy steels.[11]

Recent developments have led to the wider use of the inert-gas-shielded-metal-arc welding processes. In early attempts to weld the carbon steels by such processes the use of argon as the inert shielding gas was found to be unsatisfactory, due to poor metal transfer conditions, and a poor bead contour resulted. The use of a consumable mild steel core wire with a gas mixture containing 5% oxygen and 95% argon, however, gave much better results with a more spray-like form of metal deposition.[12] High speed photography revealed that the metal drop rate was approximately 40 times greater with the argon-oxygen mixture than with the pure argon atmosphere. The rimmed-steel core wire which is used for the standard mild steel flux-coated metal-arc electrode is not suitable for the oxy-argon gas welding process, a killed steel wire containing a small excess of deoxidising elements being essential if porosity in the weld deposit is to be avoided. The function of the dissolved oxygen in the core wire of the manual electrode would appear to be transferred to the type of atmosphere used in this new process and, if accompanied by a controlled deoxidation, ideal melting conditions should be present.

Very high deposition rates are possible with the automatic inert-gas-shielded-arc welding processes due, largely, to the fact that high welding currents can be used. The welding current is fed to the core wire close to the arc and overheating troubles are thereby avoided .In addition, the inert atmosphere enables a high metal recovery to be obtained compared with that which is given by the usual manual electrode processes. The following figures[12] illustrate the large improvement in metal deposition rate which is possible with the inert-gas-shielded process using a consumable electrode. The higher current deposition conditions for the inert gas process are employed when a deep penetration weld is required.

		Flux Coated Electrode	*Inert Gas Process*	
Core wire diameter	—in.	$\frac{1}{4}$	$\frac{3}{32}$	$\frac{1}{8}$
Welding current	—amp.	250	350	500
Deposition rate	—lb./hr.	4·3	9·5	15·2

One practical application of the inert-gas-shielded-metal-arc process may be quoted in connection with the butt welding of seams in carbon, alloy and stainless steel pipes. This process has been found particularly useful for the initial root deposits[13, 14] in the prepared joints of pipes which are too small in diameter for any interior sealing runs to be applied. The use of an interior backing ring can be dispensed with and the degree of penetration can be controlled accurately so that a smooth bead surface, uniform in size, is produced on the inside of the pipe. A separate supply of inert gas may be maintained in the pipe itself to prevent oxidation of the under surface of the weld metal. The existence of a smooth internal weld surface is, of course, of considerable importance in pipelines carrying corrosive liquids.

Stainless Steel Deposits

The Class 6 type of electrode has been modified by the addition of metal powders to the electrode coating so that weld metal deposits can be produced containing up to 6% chromium, together with smaller amounts of nickel and molybdenum as required. These electrodes have been developed recently for the metal-arc welding of the more highly alloyed structural steels and components designed for creep resisting purposes.

For the metal-arc welding of the stainless steels, however, the composition of the electrode core wire is normally similar to that of the material to be welded, and only small adjustments in weld metal analysis are attempted by additions of metal powder to the electrode coating. The argon-arc process will, no doubt, continue to find increasing application in the welding of the stainless steels, although at the present time the bulk of welding fabrication is carried out with the metal-arc process.[15] The composition of the weld metal deposits given by modern coated metal-arc electrodes is controlled to very close limits so that a structure is produced having the most suitable mechanical properties and metallurgical characteristics.

Fig. 9.—Flake graphite structure in nickel-iron alloy weld deposit on cast iron. ×750

The troubles encountered during the early days of stainless steel welding, due to the intergranular precipitation of carbide, have been overcome by the use of stabilising elements. Stainless steel plate material used for welding normally contains small amounts of titanium, while many present day electrodes give weld deposits containing a controlled quantity of niobium. Niobium is used in preference to titanium because of the excessive loss of the latter element which occurs during transfer across the metal arc. The stabilising additions effectively prevent any formation of chromium carbide when the welded structure is maintained for any length of time at a temperature in the region of 650° C., so that present day welded components can be quite free from intercrystalline attack under corrosive service conditions. These stabilising elements can have adverse effects, however, where their presence in the steel causes the single phase austenitic type of structure to be replaced by a duplex structure. This is often the case when molybdenum additions are made to improve the resistance of the steel to attack by acids, and in stainless steels of the 18/8 type containing molybdenum, quite large amounts of ferrite may be present in the duplex structure. It is believed that the stabilising elements, in producing stable carbides, tend to reduce the quantity of carbon in solution and this, in turn, reduces the austenite stability at room temperatures.

If an undue amount of ferrite is present in a duplex weld deposit, the corrosion resistance of the weld metal may be lowered and its mechanical properties severely affected by long time service in certain ranges of temperature. If a stainless steel with a duplex austenite-plus-ferrite structure is maintained for any length of time at a temperature between 500 and 850° C., the ferrite areas may be transformed into a new phase known as "sigma," which is hard and brittle, while at lower temperatures, in the 350–525° C. range, a secondary hardening effect may occur. This latter effect, which produces what is known as the 475° C. embrittlement, has received much attention recently[16], and its occurrence appears to be dependent on the amount of ferrite present and on the chromium content of the ferrite. Fortunately, the harmful effects of these microstructural changes in the weld metal can be minimised by a careful limitation of the amount of ferrite present in the original structure, this being effected usually by a judicious increase in the nickel content of the weld metal.

Fig. 10.—Spheroidal graphite structure in nickel-iron alloy weld deposit on cast iron. ×750

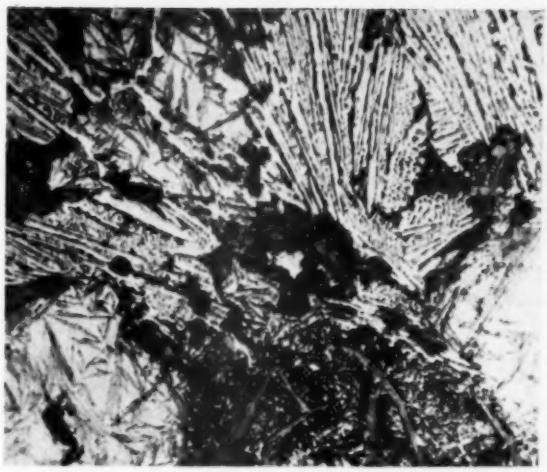

Fig. 11.—Heat affected zone beneath nickel-iron alloy weld deposit on cast iron. ×750

Weld deposits which have a completely austenitic type of structure have been found to possess poor resistance to hot cracking when subjected to stress at temperatures approaching that of the solidus, but the presence of a small amount of ferrite in the deposit appears to prevent this particular type of intergranular weakness.[17] It has been found that the presence of approximately 5% of ferrite in the structure is sufficient to prevent the occurrence of hot cracking, and provided the ferrite content of the metal does not exceed 10% the deleterious hardening effects mentioned earlier do not become unduly pronounced. These findings have resulted in the production of the recent ferrite-controlled electrodes which are finding widespread use at the present time.

Welding of Cast Irons

Recent years have seen the development of new and improved electrodes suitable for the metal-arc welding of cast iron in general, and the new ductile nodular type of cast iron in particular. These electrodes have a pure nickel or a nickel-iron core wire[18], and show distinct advantages over the older type of electrode based upon a bronze or a Monel metal core wire.

The flux coatings used with the nickel and nickel-iron alloy core wires are basic in nature and contain a high percentage of graphite. Very steady arc conditions are obtained with this type of coating, and the weld deposits contain free graphite in the form of fine flakes or nodules, as shown in Figs. 9 and 10. This type of structure is readily machinable, although precautions have to be observed in the case of the nickel-iron alloy deposits to avoid local work-hardening effects.

The welding qualities of metal-arc electrodes based upon the nickel and nickel-iron alloy core wires are, in general, superior to those based upon bronze and Monel metal core wire, and, in addition, the higher tensile strength coupled with good ductility of the nickel-iron deposit makes this type of electrode especially suitable for welding the new ductile cast irons.

With all methods of fusion welding cast iron, there is a narrow zone immediately beneath the weld metal which

is intensely hard and has a microstructure similar to that shown in Fig. 11. In the example shown, the maximum hardness of the heat affected zone was 440 D.P.N., but subsequent heat treatment of the whole piece at 650° C. reduced the maximum hardness to 210 D.P.N. If machining operations after welding are likely to penetrate into the heat affected zone, therefore, it may be necessary to apply a tempering treatment after welding in order to secure easy machinability. The hardness and depth of the hardened zone appear to be affected to some extent by the thermal conductivity of the metal used for the weld deposit, rather than by its melting point, as is indicated by the following results.

Weld Metal	*Maximum Hardness of Heat Affected Zone*	*Depth of Heat Affected Zone*	*Melting Point of Weld Metal °C.*	*Thermal Conductivity of Weld Metal c.g.s. units*
Nickel or Nickel-Iron Alloy	450 D.P.N.	0·9 mm.	1450	0·03 (Ni-Fe)
Monel Metal	450 D.P.N.	1·6 mm.	1350	0·06
Bronze	850 D.P.N.	1·5 mm.	1050	0·19

The extent of the heat affected zone and the maximum hardness in this zone also depends on the plate temperature before and during welding, and on the welding current, and in this connection the nickel and nickel-iron alloy electrodes show an advantage in that, with them, satisfactory welding conditions may be obtained at a lower welding current than with the copper-base alloys. Thus, where subsequent heat treatment of the cast iron is not possible or economic, the danger of hard areas being encountered in the parent metal during machining is less when the nickel or nickel-iron alloy electrodes are used.

Gas Welding

Although the gas welding process is widely used for the welding of the non-ferrous metals, it does not find the same application for the welding of the more massive ferrous sections. In certain instances, however, the gas welding process does show an advantage over the metal-arc process.[19] Thus, the joining of thin steel sheets can be carried out more satisfactorily with gas welding than with metal-arc welding, the less intense flame temperatures permitting better control of the operation, while oxy-acetylene butt welds on pipe lines and vessels of small diameter are preferred in many cases, as uniform penetration to the bore can be obtained consistently. Branch joints on small pipe lines involving frequent changing in welding position are also made more readily by gas welding.

Recent developments in the gas welding of iron and steel have been associated chiefly with improvements in the design of the welding torch and in the methods of handling the components being welded. Oxy-acetylene welding torches have been designed with dual tips to perform two operations simultaneously.[20] As the torch is moved along the joint to be welded, the first tip, with a small diameter nozzle, effects the necessary preheating and also trims off unwanted burrs and cleans the prepared edges. The second tip provides the higher temperature flame required for the welding operation. With an arrangement of this type, the speed of welding is claimed to be more than double that obtainable with the more conventional single nozzle torch. It is possible to extend this idea and utilise a multiple tip burner where a third small flame, following behind the welding flame, impinges on the finished weld and thus provides slow cooling conditions for the deposited weld metal.

The improvements in handling methods for use with the gas welding process are perhaps of more interest to the mechanical engineer than to the practical metallurgist. For longitudinal seams on pipe work and thin sheet steel vessels, the material may be fed by rollers at a constant speed under a torch held in a fixed position; continuous automatic welding is possible in this way. With circumferential seams, the work may be rotated under the fixed welding head. Other mechanical handling devices allow a number of joints to be welded at the same time, and in such cases the work-piece is usually stationary and two or more welding torches are moved automatically along the seams. In this way the speed of production may be increased greatly and the amount of distortion reduced.

Conclusions

The most outstanding recent developments in the fusion welding of iron and steel may be summarised under three headings.

(1) The increasing use of low-hydrogen electrodes for the metal-arc welding of the low-alloy steels. The application of these electrodes can be expected to facilitate the fabrication of highly stressed components in the medium and high tensile strength steels.

(2) The introduction of the inert-gas-shielded-metal-arc process with a consumable mild steel core wire. The welding of mild steel by this process has been made possible by the use of argon containing a small amount of oxygen. The process would seem to have a considerable future and the high deposition rates now claimed for this process are in excess of those which can be obtained with any other process.

(3) The development of ferrite-controlled metal-arc electrodes for the welding of the stainless steels. These electrodes have provided a new standard of safety in the fabrication of equipment for the chemical, oil and engineering industries. This development has resulted from a greater understanding of the metallurgical factors which influence the quality and properties of welds in stainless steel, and has necessitated a high degree of precision in the control of the chemical analysis of the deposited weld metal.

Acknowledgments

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Modern Heat Treatment Practice

Report of B.I.S.R.A. Conference

The topics at a recent conference on heat treatment ranged from flame hardening to isothermal treatment, and from the heat treatment of large forgings to the measurement and control of temperature. A full report of the conference will ultimately be published by the British Iron and Steel Research Association ; in the meantime a brief account of the proceedings is presented here.

A CONFERENCE on heat treatment practice, organised by the Metallurgy Division of B.I.S.R.A. was held under the sponsorship of the Thermal Treatment Sub-Committee at Ashorne Hill, near Leamington Spa, from 15th to 17th June, 1953. The chairman of the conference was Mr. H. H. Burton, C.B.E., and the vice-chairman, Mr. W. C. Heselwood. Among the 230 participants were representatives of steelmakers and users of engineering steels, the latter including motor car manufacurers, furnace builders, instrument makers and others.

Mr. Heselwood opened the conference with a review of the work of the Thermal Treatment Sub-Committee (of which he is chairman) over the past 17 years ; then followed the technical sessions on the heat treatment of engineering steels ; the heat treatment of large forgings ; the heat treatment of surfaces ; surface treatment (involving a change in composition) and heat treatment of surface-treated components ; isothermal heat treatment ; and temperature measurement and control ; each session consisting of papers and discussions.

Films were shown on flame hardening, bainite formation and a modern pyrometer, and there was an exhibition of modern temperature measuring and controlling instruments.

SESSION I — HEAT TREATMENT OF ENGINEERING STEELS

(a) Steels Available for Engineering Purposes (not requiring surface treatment)

By H. Bull, A.Met., F.I.M.
Brown Bayley Steels, Ltd.

In introducing his subject, Mr. Bull gave a general account of the wide range of alloy and carbon steels available to the engineer, and indicated the extent of the work involved in producing those specifications. The particular steel chosen would depend on the service conditions under which the finished part was to operate, and a particular combination of strength, ductility, hardness, wear resistance, corrosion resistance, dimensional stability, etc., would be required. The correct balance of composition and heat treatment was necessary if the required properties were to be attained, and in some cases the steel might be supplied in the heat treated condition. In other cases, however, the heat treatment operation had to be carried out after machining, a situation which called for co-operation between steelmaker and user where there was any doubt as to the properties attainable by such a procedure.

Mr. Bull suggested two directions in which progress by the steelmaker would be helpful : (*a*) the production of alloy steel ingots free from surface defects ; and (*b*) the development of isothermal treatments to produce material suitable for direct application straight from the rolling mills. In the course of his lecture, he described some of his findings on the necessity for working ingots to induce transformations, and referred to his experiences in the treatment of ball bearing steels. The importance of tests to determine the suitability of a steel for a particular service was illustrated by reference to tests for temper brittleness, ageing, fatigue resistance and impact resistance.

In conclusion, Mr. Bull thought that the co-operation of steelmakers and users would result in new steels, more specifications and a better understanding of their treatment.

Discussion.—Normally the designer would work from the tensile properties given in a specification, and it was felt that the lack of other information was often responsible for steels of a higher alloy content than necessary being used. A reduction of the number of specifications might help to minimise the designer's problems.

Because of the long times involved, heat treatment directly after hot rolling was considered to be likely to prove uneconomic. With high carbon chromium steels, quenching followed by annealing greatly reduced the time necessary for softening. It was suggested that micro segregation rather than macro segregation might be the cause of some of the defects. Temperature gradients in the furnace were not a problem with high carbon chromium alloys, but slow cooling was essential to avoid the production of flakes. Grain boundary networks could be removed by heating the steel at 950° C. and then transferring to a furnace at 720° C.

(b) Problems Associated with the Heat Treatment of Engineering Steels

By H. H. Jackson, A.F.R.Ae.S., F.I.M.
The Standard Motor Co., Ltd.

Mr. Jackson felt there was considerable scope for a wider application of the steels at present available,

particularly the lower alloy steels. There was no doubt that in many cases it would be possible to use cheaper, lower alloy materials than was at present the case, and he enunciated the principle that the various parts of a component need only possess adequate properties to withstand the applied stresses in those particular parts. Economies could be effected in practice by fabrication or by part-heat-treatment. It was, however, essential to consider individually every component, and very thorough tests were necessary to ensure the success of such innovations. Moreover, it would be evident that the heat treatment practices adopted should be perfectly consistent and reproducible.

In illustration, Mr. Jackson gave a comprehensive account of various applications of this principle.

Discussion.—The subject of grain size was raised in the discussion, and it was pointed out that grain size was usually only specified for some of the case-hardening steels. Grain sizes of 1–5 or 5–8 were obtainable, but such limits as 3–5 were difficult and expensive to achieve. Hardenability was greater and more consistent with coarse-grained steels and they also carburised more rapidly. The grain size of a steel as machined was often different from the inherent grain size, and it was sometimes very difficult to coarsen by heat treatment. Grain size limits were specified to ensure consistency, in that grain size affects the heat treatment response and, in consequence, the degree of distortion. A uniform grain size within the component was desirable to avoid cracking.

Owing to steel coming from the steelmaker via the rolling mills to the user, control of steel consistency was difficult. Consistency of such properties as susceptibility to temper brittleness was also a problem. The demand for high Izod values was questioned and also the relationship between Izod and fatigue properties. For various automobile parts, high toughness was essential to withstand the occasional overloads to which they were submitted, a factor not usually allowed for in rig tests. High Izod values were also necessary for steels submitted to sub-zero temperatures, partly to allow for the possibility of the transition temperature being above the working temperature. It was put forward that components having to resist shock loading and fatigue conditions required notch toughness to retard the propagation of a fatigue crack after its initiation. An improvement in the impact properties of the steel was achieved by water quenching from the tempering temperature. The compressive stresses introduced in this way occurred to a sufficient depth to permit some machining, but it was emphasised that the water quench had to be symmetrical and the machining concentric if distortion were to be avoided. Wöhler tests showed an improvement in fatigue life but not an increase in the fatigue limit.

SESSION II—HEAT TREATMENT OF LARGE FORGINGS

Metallurgical Problems

By T. R. Middleton, B.Sc., F.I.M.
English Steel Corporation, Ltd.

The heat treatment of large forgings, whether for boiler drums, steam turbine rotors, alternator rotors or other end products, calls for specialised procedures, in the development of which Mr. Middleton said that the main consideration was the uniformity of treatment during both heating and cooling. For example, whereas small forgings could be left to cool on the shop floor before heat treatment, it was necessary, when dealing with forgings of up to 25 tons in weight, 40 ft. in length and 12 ft. in diameter, to charge them into a furnace, immediately after forging, for cooling through the transformation range under carefully controlled conditions. In the absence of such precautions, high stresses might be generated within the forging, which would lead to the formation of clinks or similar defects. In some cases the furnace cooling was followed by the heat treatment necessary to attain the required mechanical properties without the forging being allowed to cool to room temperature until the heat treatment was completed. On the other hand, there were instances when it was necessary to rough machine the forging before treatment in order to remove surface defects or to reduce the bulk so that the best possible mechanical properties could be attained.

The final treatment might consist of air hardening or oil quenching, followed by tempering, depending on the particular steel used, the size of the forging and the properties required. It was most important that the furnace used should be appreciably larger than the forging, and capable of uniform heating, as otherwise differences in temperature in parts of the forging might result in the transformation of one part in the pearlitic range and of another part in the bainitic range, with consequent distortion. Mr. Middleton gave numerous examples of heating cycles necessary for various heavy forgings and described the use of both horizontal and vertical furnaces. It was not usual to quench large forgings from the tempering temperature, and in cases where freedom from internal stress was essential, furnace cooling from this temperature would be adopted.

In the case of forgings for use at elevated temperatures, such as turbine rotors, freedom from internal stress was particularly essential, as otherwise distortion would occur in service. For that reason a stabilising or stress-relieving treatment was often introduced after considerable machining had been done on the forging, the temperature of treatment being below that employed for tempering, so that essential mechanical properties were not affected.

Discussion.—During the discussion it was claimed that electric furnaces gave the least trouble with regard to top and bottom temperatures, and the use of high speed air circulated furnaces was suggested as a further improvement. It was also pointed out that large forgings could be rotated to increase the uniformity of treatment. With carbon steel forgings, due consideration had to be given to the effects of the different cross-sectional areas of the various sections.

In one instance, incomplete quenching of a nickel-chromium-molybdenum (En 25) steel had resulted in the development of cracks, but generally speaking quenching until cold was considered to be fatal. It was noted that the En specifications were not applicable to steel above 6 in. in diameter. Although water-soluble-resin type quenches—intermediate between oil and water—were available, their use was not considered as cooling rates faster than oil were not required. Control of cooling effects was mainly achieved by variations in alloy content. There was very little experience of oil quenching of large forgings in the U.S.A., but it was felt that, provided the internal stresses developed on quenching were low and symmetrical, there would be freedom

from cracking. In view of the fact that most of the cracking occurred at the transformation temperature, it was suggested that air cooling to this temperature might be possible, with resulting economy. This was not considered practicable due to handling problems.

Basic electric steels were prone to the development of hair line cracks or flakes, but provided the cracks had a favourable orientation, were not oxidised, and the forging was not too large, the cracks would weld up on forging. There was an incubation period before the onset of cracking, but this was affected more by the size of the forging than the alloy content. Small pieces had a longer incubation period than larger ones. An example was given of cracks being initiated after two weeks and continuing to grow up to twelve months later. In the U.S.A., elaborate precautionary treatments were carried out, but basic open hearth steels were rarely used as they had a high hydrogen content and low transverse properties.

It was generally agreed that concentration of the hydrogen in the retained austenite was the cause of hair line cracks, although it was observed that the development of hair line cracks was possible without the presence of retained austenite. The diffusion of hydrogen obeyed a form of square law, the partial pressures deciding the direction of diffusion; in the furnace, however, it was thought that the reintroduction of hydrogen into the steel was unlikely. The appearance of the flakes gave an indication of the stage at which they were produced.

SESSION III—HEAT TREATMENT OF SURFACES

(a) Induction Heating Processes

By R. J. Brown, F.I.M., A.M.I.Mech.E.
Morris Motors, Ltd.

After an introductory treatment of the principles of induction hardening, Mr. Brown considered the ranges of application of rotary and valve generators, and dealt also with their respective efficiencies. The higher the frequency of the current in the inductor, the shallower the heating effect in the component, so that the lower-frequency rotary generators were used for through heating and for deep surface heating, whilst the valve generators were used mainly for shallow hardening, and also for precise local treatment, brazing and soldering, etc. Mr. Brown pointed out that the cost of plant and experimentation had to be allowed for when considering the possible applications of induction treatments.

In discussing inductor design, particular attention was given to the inductor gap effect and the means of overcoming it. The principles of single turn and multi-turn coils were also outlined. Two methods of application, static (in which the component being treated remained stationary in the inductor) and progressive (in which the component moved through the inductor), were described and numerous examples given. These included surface hardening of shifter shafts, gudgeon pins, ball races, and gears, the particular problems associated with the surface hardening of gears being emphasised.

In conclusion, Mr. Brown dealt with the requirements of material to be surface hardened and the properties to be expected, pointing out that the carbon content should be sufficient to give the desired hardness, and that it was most important that the material should be free from decarburisation on those surfaces to be hardened. Both hot-rolled and bright-drawn bar steel had appreciable surface decarburisation, and that fact, more than any other, had limited the adoption of induction hardening for many simple cylindrical components, as the cost of removing the decarburisation often exceeded the saving made by using induction hardening.

(b) Flame Hardening Processes

By M. L. Becker, Ph.D., B.Met., F.I.M.
Head of the Metallurgy Division, B.I.S.R.A.

The objects of flame hardening, said Dr. Becker, were to give increased strength and resistance to wear, and to improve fatigue and impact properties. It was possible to produce uniformly deep cases by surface hardening, and unless high core strengths were required alloy steels were often unnecessary, although there was nothing to prevent them being used for flame hardening, provided due precautions were taken. By the use of surface hardening, economies could be made in heat, time, plant and space.

Compared with carburising as a means of case hardening, there was an ease of local application, and stopping-off was unnecessary. Furthermore, since the core was not heated, distortion was generally of negligible proportions, so that costly final grinding might be eliminated. The properties of flame hardened and case hardened steels were compared and the effect of case depth on notch fatigue was discussed.

Successful flame hardening involved proper control of the rate of heat input, the maximum temperature reached and the rate of cooling. The most important factor governing the rate of heat input was the flame temperature, although, of course, the size of burner and rate of movement of the surface through the flame were also important. Flame temperatures initially employed were about 3,200° C., whereas temperatures of 2,200° C. were now being used. The maximum temperature reached could be controlled automatically by means of a radiation pyrometer, and an instrument suitable for this purpose, and effective from 200° to 1,400° C., was now available.

The application of flame hardening and the machines used in carrying out the process were described and illustrated by reference to such components as gears, crankshafts and lathe beds.

Joint Discussion.—Removal of up to $\frac{1}{32}$ in. from the surface of bar stock was usually necessary to ensure the absence of decarburisation and surface seams. The H. F. process was more sensitive than the flame process to the effect of prior structure, due to the increased rate of heating which, however, resulted in a narrower intermediate zone. With the shorter heating times, excessive grain growth did not occur, and the higher temperature possible increased the carbide solution rate. The uniform dispersion of cementite was not so necessary with the higher carbon steels, but the relation of carbon content to machinability had to be kept in mind. Within certain limitations, a saving of alloys could be effected by the use of surface hardening.

The development of surface compressive stresses by surface hardening was mentioned, and it was emphasised that the adjacent tensile stresses must not meet the surface at a fillet or high stress zone. The presence of the compressive stresses brought about an improvement

in the endurance ratio which increased in the order—induction hardening, flame hardening, nitriding, carburising.

Small diameter tubes had been satisfactorily treated, using a floating induction coil which followed any movement of the tube.

SESSION IV—SURFACE TREATMENTS (INVOLVING CHANGE IN COMPOSITION) AND HEAT TREATMENT OF SURFACE-TREATED COMPONENTS

By C. C. Hodgson, F.I.M.
Leyland Motors Ltd.

The main surface treatments involving change in composition in use in the engineering industry were carburising and nitriding and combinations of the two. Nitriding could produce harder but shallower cases than carburising, and had the outstanding advantage that no quenching from a high temperature was involved. On the other hand, the process was a lengthy one and the steels suitable for the process were limited.

In dealing with the carburising process, Mr. Hodgson said that the essence of the process was the production of a case of suitable depth and hardness, without distortion. Consideration was given to many aspects of the process, including the quenching operations. He thought that the heat treatment processes were tending towards simplicity, and were assisted in that direction by improvements in component design. Generally speaking, the quality of a case-hardening steel was assessed on the mechanical properties of the core, although in many instances the user was more interested in the properties of the case, and Mr. Hodgson suggested that a study of the properties of high carbon steels, representing cases which might be obtained with the various alloy case hardening steels in use to-day, might usefully be undertaken.

Although the older methods, using solid or liquid carburising agents, were still responsible for a large amount of carburised work, most development had occurred in the field of gas carburising. There were several methods of gas carburising in use, and in describing them, Mr. Hodgson drew attention to their advantages and disadvantages. He also considered the carbo-nitriding process, pointing, out that the hardness was dependent on the nitrogen and carbon contents, and added that low temperatures gave a high nitrogen content and vice versa.

Discussion.—Although the theory of the gas carburising process was complex, in practice the points of chief importance were, low carbon dioxide (less than 0·2%) and dewpoint, and the presence of sufficient hydrocarbons. The figures mentioned for the cost of instruments were: flow indicators £20, flow recorders £45, gas analysis and dewpoint instruments £1,000–£2,000. An infra-red absorption method had been used for the recording of carbon dioxide and cost less than £100. Fracture tests or magnetic tests on a wire continuously passing through the furnace at the same rate as the work had been employed as a means of control. It was suggested that as the calorific value of the gas was closely related to the percentage of hydrocarbons present, it should offer a method for its recording by means of a cheap instrument.

With gas carburising employing a direct quenching plant, the carbon content of the steel surface had to be kept at about 0·7%. This could be achieved by cutting off the carburising gas in the final stages and allowing a diffusion period. The gas carburising of low alloy En steels might present difficulties as they were sensitive to variations in time. Inherent grain sizes of 6–8 were usual, but for carburising processes an austenitic grain size of 5 or less was desirable. The alternative, the use of a high temperature, might result in low Izod values. Reheating in a cyanide bath to refine the grain was not reliable. The possibility was mentioned of cracks occurring between the case and the core which did not run into the surface. A desirable gas carburising cycle was necessary to obviate double quenching and to maintain a small grain size.

It was said that the cracking of some high chromium steels occurred due to the case transforming before the core, but that could be prevented by rapid cooling in air or oil from the carburising pot.

In the discussion on carbo-nitriding, it was stated that cases of 0·020/0·030 in. were possible, but that 0·005 in. was more usual. The wear resistance was greater than for cyaniding, and as carbon was absorbed at a lower temperature, less distortion occurred. Carbo-nitriding of En 18, En 352 and En 355 was troublesome.

One member had carried out unnotched Izod tests on high carbon steels, and another had used test pieces which had been carburised and heat treated after notching. The impact value was greatly reduced by the presence of the case.

Isothermal diagrams for the En 25X series steels containing 0·9% carbon were being prepared by B.I.S.R.A.'s Isothermal Transformations and Hardenability Group. On the distortion of bores, it was said that the case depth and the carbon content of the core affected the degree of distortion, and the design of the component affected the direction of distortion, i.e. either contraction or expansion.

It was claimed that martempering, after carburising or cyaniding, reduced the distortion and produced a tougher case for a given hardness. With the martempering process, 50% was carried out in hot oil, and 50% in salt baths at about 200° C. A nitrite/nitrate salt bath was used, but it had to be preceded by a neutral bath after cyaniding to avoid explosions. Martempering in an air furnace after cyanide treatment of En 24 had been practised, but such a procedure was not possible with low alloy steels.

On the subject of nitriding, reference was made to the use of multi-stage units. The use of 2- or 4-stage treatments had been employed to break down the film developed on austenitic stainless steels, and so make the processing of those steels possible. A 3-stage process described consisted of a stage for heating to temperature, a nitriding stage, and a diffusion stage. For some steels, it had been found possible to reduce the time of treatment from 72 hours to 12 hours and an improvement in fatigue properties and surface hardness had resulted.

SESSION V—ISOTHERMAL HEAT TREATMENT

Recent Developments, including a Description of the Work of the Isothermal Transformations and Hardenability Group

By H. W. G. Hignett, B.Sc(Eng.), F.R.I.C., F.I.M.
The Mond Nickel Co., Ltd.

Starting with the pioneer work of Bain and Davenport, Mr. Hignett traced the growth of our knowledge of isothermal transformations by reference to work carried

out on the subject, and pointed out that much remained to be done to determine the quantitative effects of variations in composition. The need to use laboratory-made rather than commercial steels for such work was emphasized by some figures for the isothermal transformation characteristics of samples from different positions in a 4-in. diameter billet, which showed considerable variation.

Most alloy steels were still oil-quenched and tempered in the straightforward way, and the S-curve gave little quantitative information which could be applied to steels cooled continuously. A number of methods of calculating the course of transformations under continuous cooling conditions had been suggested, but none had achieved much success. The isothermal transformation diagram was, however, of value in fundamental research work, because it gave a more detailed picture of the transformation habit of a steel than did continuous cooling curves. It was also useful in deciding the correct treatments for isothermal annealing, austempering and martempering.

Fully bainitic structures were developed in austempering, by quenching into a lead or salt bath at the appropriate transformation temperature, and the risk of cracking or distortion associated with the martensite transformation was avoided. Considerable improvement in impact results could be achieved by tempering after austempering, even when a factor of safety in time had been used in interpreting the S-curve, a precaution also advisable in isothermal annealing. Martempering was a means of minimising distortion and cracking, whilst at the same time hardening fully, by quenching to a temperature just above the M_s temperature, holding until the temperature equalised throughout the part (without bainite formation), and cooling in air

Discussion.—In practice, the slow cooling of large forgings was essentially isothermal, and the S-curve therefore, was of use in such cases. The relation between continuous cooling and the S-curve presented certain difficulties, e.g., if the transformation commenced in the pearlitic range, the matrix changed and the S-curve was useless ; if it commenced in the bainitic range, then the prior time in the pearlitic range made the final effect uncertain. It was pointed out that S-curves were plotted from results on wire or bar samples, and that in application, a factor of $\times 2$ or $\times 3$ might be necessary to allow for any lack of uniformity.

In the employment of salt baths for quenching, agitation of the salt by rotating paddles, or an immersed spray, was said to increase the cooling rate considerably. It was also pointed out that contamination of the salt would also affect the cooling rate.

In discussing austempering, it was stated that the bainitic reaction did not go to completion, and that the residual austenite transformed to martensite on final quenching, so that a final tempering operation might be necessary.

" Why do some steels require double treatment ? ", was asked, and in reply it was said to be a problem of stabilisation of the retained austenite. A lower hardness was obtained by the double treatment. There was some debate as to the relation between retained austenite and any cracking which occurred.

Some doubt was raised as to the existence of an M_f temperature and this brought forth one definition of the M_f temperature as that at which the martensitic transformation had finished, which might occur at less than 100% martensite. Although a fully martensitic quench was desirable, it was thought to be extremely difficult to obtain, or wasteful of alloys. On the other hand, there was some support for the contention that small amounts of bainite were more dangerous than large amounts.

Three factors were put forward as having the main effect on the Izod value, namely, (1) the concentration of stresses, (2) the presence of tri-axial stresses, and (3) the impact effect : the third factor was said to be of least importance. The transition temperature also varied with the design of the notch, stress concentration and strain rate. There was some criticism of the specifications for impact tests, but it was pointed out that they were under review.

SESSION VI—TEMPERATURE MEASUREMENT AND CONTROL

Recent Developments in Heat Treatment Processes

By T. Land, M.A. (Cantab), F.Inst.P.
Land Pyrometers Ltd.

Most heat treatment operations did not present any problems in pyrometry, said Mr. Land, but there were some connected with work which was at a different temperature from its surroundings, such as in flame and induction hardening processes, hot masses in the open air, and the true temperature of cold steel in a furnace. In discussing some of these difficulties, he said that the most rapid temperature measurements were made using radiation pyrometers, the main drawback of which was the emissivity error. The use of a hemispherical reflector having direct contact with the work had helped to overcome this error, the alternative being a contact plate, with a thermocouple attached, backed by a refractory brick. The properties of photo-electric, photo-emissive and conductive cells, and their sensitivity to different ranges of wavelength, was dealt with, and a graph was shown of mean error against wavelength at various temperatures.

Discussion.—In the discussion, the pyrometer described in the paper, which employed a contacting hemispherical reflector to obtain " internal " black body conditions, was said to read a temperature, after 5 seconds delay, corresponding to that of the forging at a small depth below the surface. The depth was about $\frac{1}{8}$ in. for steel. The effect was due to the bending of the isothermal lines towards the surface immediately below the contact head. A uniform heating of the scale was apparent on removal of the contact head.

Of the various other pyrometers mentioned, a number of total radiation types were said to have guaranteed reproducibility, but not accuracy. Focussing on the internal end face of a tube which projected into the furnace would increase the accuracy of the temperatures measured, but the advantage of sighting the job would be lost. With the flame hardening process, the depth of case was controlled by the surface temperature recorded on a Milliscope : the true temperature of the surface was not so important. Some radiation pyrometers were claimed to be quite accurate with the advantage of operating speeds faster than thermocouples.

The tolerances of thermocouples were said to be well known and were given in B.S.H.41. The greatest inaccuracy was thought to occur in the compensation of the cold junction. It was pointed out that thermocouples

should be protected and that iron-Constantan couples should not be used above 500° C. or be exposed to an oxidising atmosphere. There was a call for a market product which would calibrate several thermocouples at a time. One method of calibration described was the use of a correction graph prepared from the differences in e.m.f. due to a standard couple and the working couple, over a range of temperatures. It was also stressed that recorders might go wrong and, as they were technical instruments, they required technical operators. The use of an " error " cam to allow for differences in temperature of the furnace and charge, was mentioned.

Owing to the difficulty of obtaining uniform heating of a charge in the furnace, it was questioned whether a very high accuracy of temperature mesaurement was necessary. A high accuracy was demanded on research work, but even on production it was said that some work required an accuracy of ± 2° C.

Extensions at Chemical Research Laboratory

DURING the year 1952 two new buildings for radiochemical and microbiological research were completed at the Chemical Research Laboratory, Teddington, and in "Chemistry Research 1952"* the Director says that this has greatly eased the position. Research has now begun that could not be tackled previously because of overcrowding. The Report points out that there has been a steady increase in the use made by industry of the Laboratory's services and a special section deals with this subject.

Corrosion of Iron and Steel

One of the discoveries made by the Corrosion Group during the year was that a suspension of sulphur in distilled water rapidly corrodes mild steel. The effect of a 20% solution was greater than that of 3% hydrochloric acid. The discovery has been applied in developing a method of etching mild steel which has advantages over the use of acids, and a patent for this process has been applied for.

Corrosion of buried pipes continued to be one of the most important problems dealt with by the Group. Two clay soils were examined in which the expected attack on buried iron had not taken place. In the first, sulphate reducing bacteria were absent owing to a toxin produced by a species of fungus. In the second and more spectacular example, it was found that tannin in the soil had almost completely prevented the corrosion of iron articles more than 2,000 years old. The latter discovery may have practical applications. The Group is at present also making an investigation of the value of cathodic protection of buried pipes.

Radiochemical Work

The Radiochemical Group has succeeded in developing an ion-exchange process for the recovery of gold and other metals from cyanide solutions used in the extraction of gold ores. The process has practical possibilities in industry. Another notable advance by the Group was the separation and determination of niobium and tantalum by chromatography: the method is being used by other laboratories. Radioactive tracer techniques have been used in the study of the mechanism of corrosion inhibitors, in chromatographic separators and in evaluation of the naphthalene content of coal tar.

Selenium and Sulphur From Wastes

Selenium is an element which is becoming more and more important in the electrical industry, but there is a world shortage of it, and the C.R.L. has begun a search for possible sources from waste materials. Flue dusts and slags are being examined, and about half the samples so far tested contain detectable amounts: new methods of analysis are being worked out.

Research on the microbiological production of sulphur and sulphide was intensified, and a marked increase in the rate of sulphate reduction, one of the requisites for a successful process, has been achieved. The main problem now is to find large quantities of a cheap fermentable waste material to use as a source of carbon. A survey of possible wastes is being made by the Intelligence Division of the D.S.I.R. So far, the C.R.L. has investigated distillers slop, dried whey, dark technical lactic acid, calcium lactate liquor, chemicals from seaweed, settled sewage and sewage sludge. The yields of sulphide were good with some of these materials but, except for sewage sludge, they are either too scarce or too expensive for a practical process as yet.

* Published for the Department of Scientific and Industrial Research by Her Majesty's Stationery Office. Price 4s. 6d. (1$ 15c. U.S.A.). by post 4s. 9d.

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Phosphate Coatings on Steel Surfaces

Continued from page 77

Other Applications

Phosphate coatings are also being employed to advantage in deep drawing operations where the benefits may include deeper draws; the elimination of some interannealing operations, pick-up and scoring; and reduced press loads as compared with those for other lubricants. Beneficial reports have also been reported in cold heading, tapering, hobbing and bar drawing.

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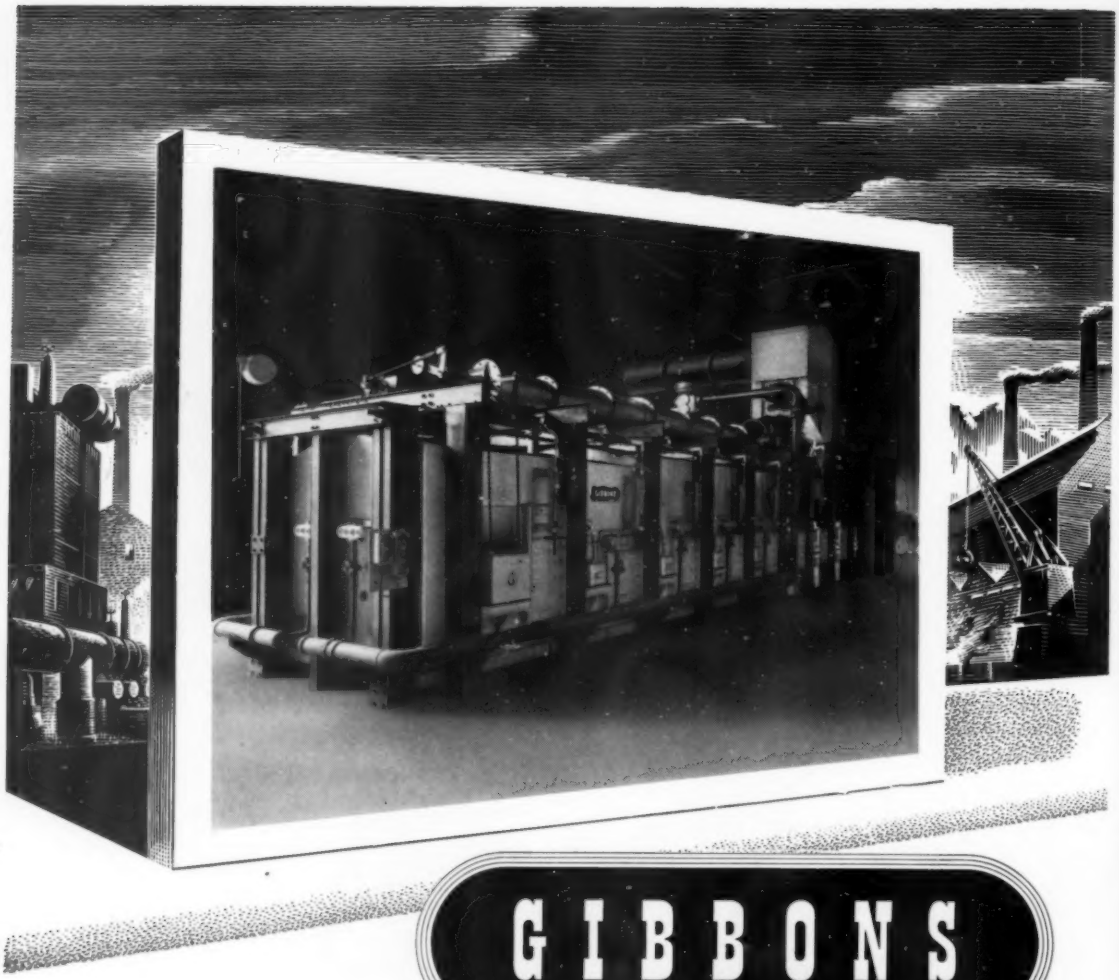

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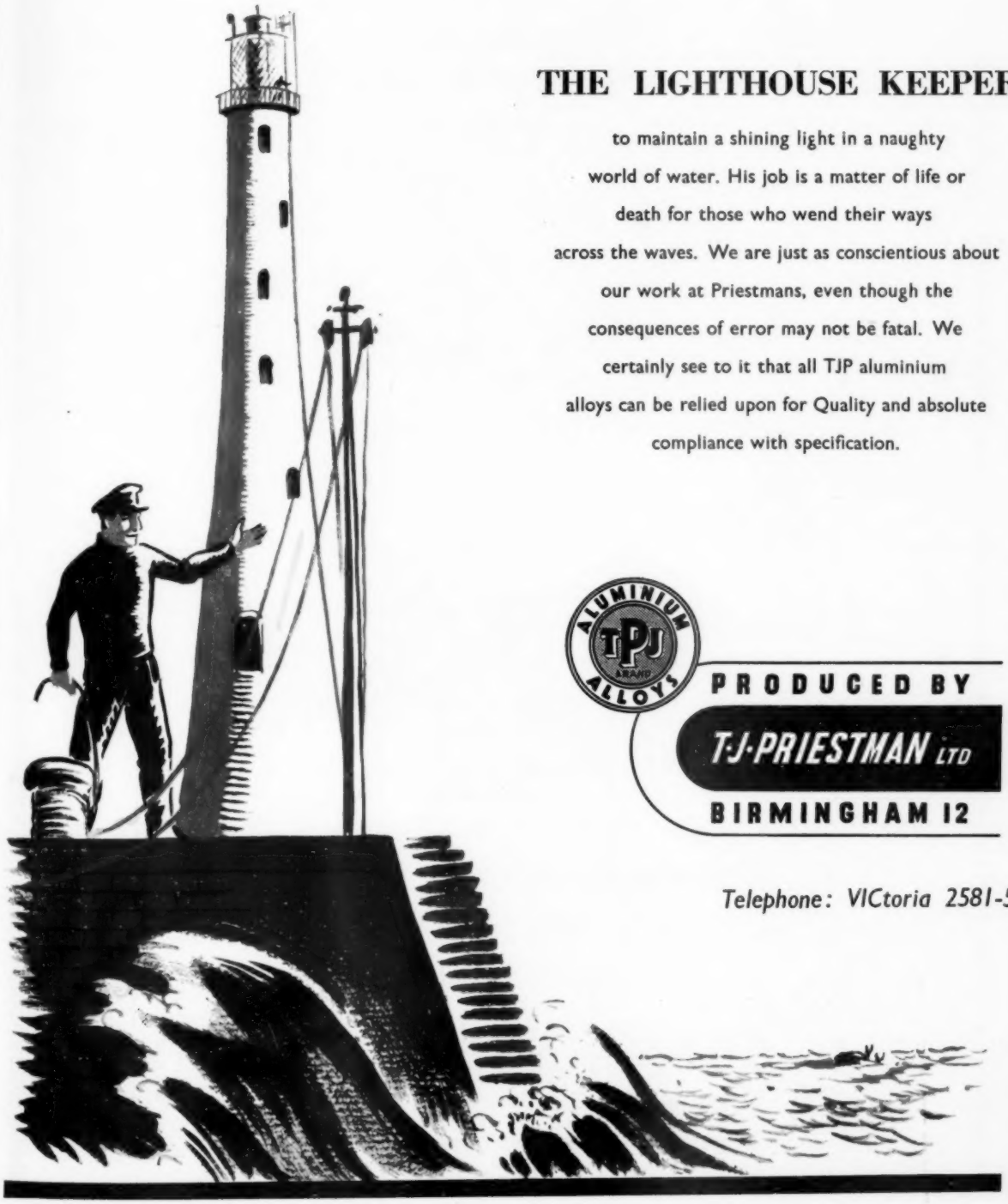

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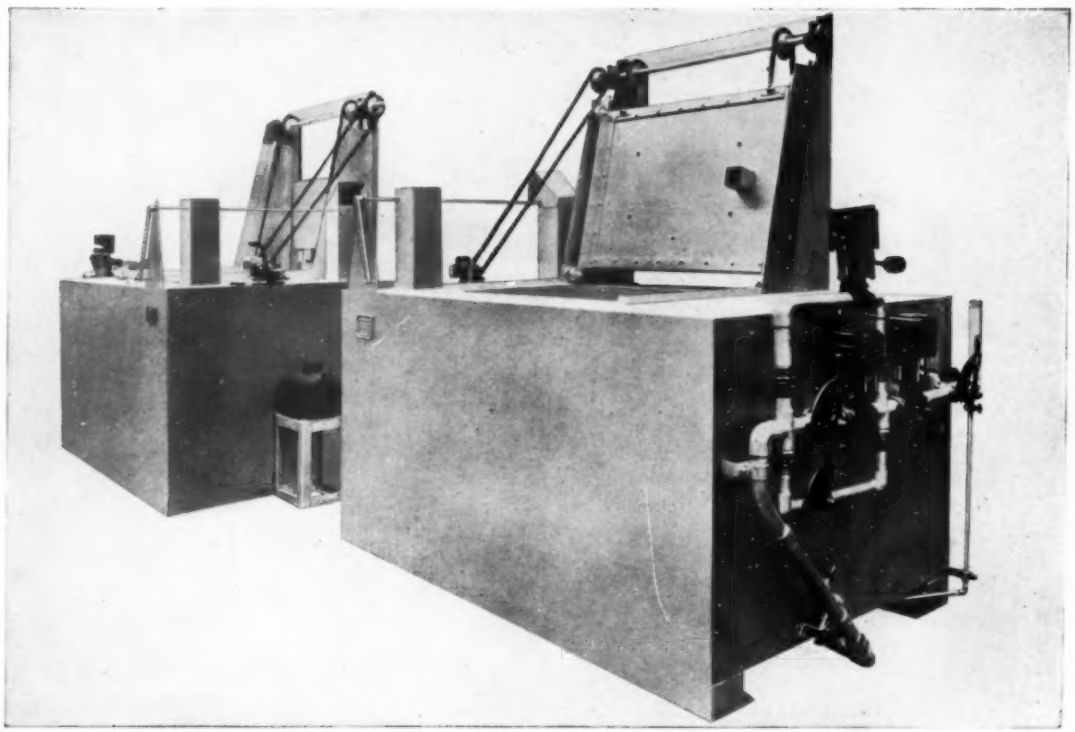

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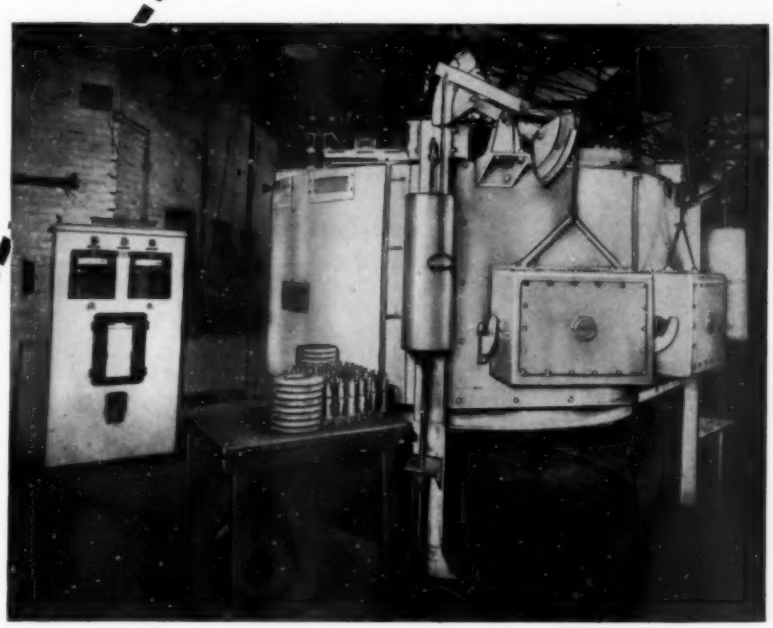

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Aluminium Passenger-Landing Pontoons

THE pontoons, designed and built by Whittingham & Mitchel, Ltd., of Byfleet, Surrey, for use on the *Orcades* and *Oronsay*, represent a particularly interesting use of aluminium alloys. Their purpose is the speeding up of the disembarkation and re-embarkation of passengers on cruising ships at points of call where no harbour facilities exist, and where the operation has to be effected by ships' launches.

These pontoons can be considered as landing stages slung over the ships' side, 2 ft. above the water level, and access to them is by means of the ships' accommodation ladders. The deck area of each pontoon is 160 sq. ft. (20 ft. × 8 ft.), and is planned to support 40 people. It will be seen that a steady stream of passengers can keep moving down the accommodation ladder until the pontoon is loaded to capacity, and that they are able to board the launch with much greater freedom than the normal one-at-a-time process from the bottom platform of the accommodation ladder.

The owners stiplulated, firstly, strength—it was considered that the pontoon should be capable of withstanding an impact equivalent to a load of 25 tons at any point, and secondly, that it must be able to float, but with only a small freeboard.

These requirements, taken together, made the use of light alloy an obvious choice, for if steel had been employed, the scantlings of the structure would have been substantially the same, but roughly three times the weight as designed (3,000 lb.). The saving is of importance for handling, and makes possible more compact buoyancy tanks.

Storage space on deck close to the accommodation ladders is not available, so they are positioned by lowering them into the water opposite their place of storage and towing them along the side of the ship to their operating positions. Here they are hoisted with tackle to 2 feet above the water level, and guys are run fore-and-aft to mooring eyes on the side of the ship. When the pontoons are rigid with the ship, the accommodation ladder is lowered so that the lower platform rests on the pontoon deck. Stanchions with guard rails give safety to the passengers. As the stations at which these pontoons operate present varying contours of the ship side, adjustable spurs are provided so that the pontoons can be firmly braced to the ship.

Pontoon being slung over side.

The pontoon in position for landing.

The adjustment is provided by means of a curved track which receives the end of the spur. The arc of the track is struck from a point eccentric to the pivot point of the spur. By pushing the outboard end of the spur down the track, the inboard end moves inwards until it makes contact with the ships' side. A locking pin maintains position.

Structurally, the pontoon is a box 20 ft. × 8 ft. × 6 ft. deep. The top side is very strong, comprising $\frac{5}{16}$ in. thick P-G-P (Positive-Grip-Pattern) Treadplate suitably stiffened by deep beams and the edges riveted to a channel framing, which is protected by a substantial elm fender. It is this reinforced deck which provides the main resistance to impact from launches coming alongside. The long sides of the pontoon are girders built from substantial T-section extrusions. Each bay, including the ends, is diagonally braced with similar sections. The bottom panel is again a channel frame, spaced with heavy gauge 3 in. diameter tubes, which transmit impact loads across this panel.

Buoyancy is provided by six cylindrical tanks, each 7 ft. 6 in. long, and of 1 ft. 2 in. diameter, located immediately under the deck plating, all seams and diaphragms being welded by the argon arc process. Each tank is provided with a drain plug in an accessible position.

Most of the metal used in the production of these pontoons was supplied by The British Aluminium Company, Ltd

Dramatic Discovery Depicted in Model

ONE of the great moments in the history of chemistry is portrayed in the model shown here.* The scene is the laboratory of Dr. Ludwig Mond in Avenue Road, Hampstead, on an evening in 1888. One of a series of experiments is in progress to discover why a carbon coating has developed on some nickel valves used in a plant for volatilizing ammonium chloride at Mond's chemical works. Earlier investigations had suggested that carbon monoxide was responsible, and the effect of finely divided nickel at about 350° C. in bringing about the decomposition of carbon monoxide into carbon dioxide and free carbon is being studied. In the apparatus on the bench, carbon monoxide was passed slowly over finely divided nickel within the tube, and, except when sampling for analysis, the deadly gas was allowed to burn at the exit end of the tube.

At the end of the day's experiments, one of Mond's collaborators had turned off the furnace burners prior to shutting down the apparatus. When the tube had cooled to about 100° C., the characteristic blue flame of carbon monoxide was seen to change to yellow. As the temperature fell lower the flame became very luminous, and when the glass tube at the exit end was heated a metal mirror formed on it. This mirror proved to be nickel. The laboratory was in the grounds of Ludwig Mond's house and when told of the unexpected turn the experiment had taken he came over to see for himself. This is the moment protrayed in the model.

Examination showed that the gas containing the volatilized nickel was nickel carbonyl. Further experiments were made in an attempt to obtain similar compounds of iron and cobalt, but whilst iron carbonyl was obtained in minute amounts no trace of cobalt carbonyl could be detected. Some years later Mond did succeed in isolating carbonyls of cobalt, ruthenium and molybdenum, but the readiness of nickel to form a volatile carbonyl, and his initial failure to obtain cobalt carbonyl, showed Mond the way to a new process for producing pure nickel from the nickel-cobalt-copper-containing ores. Thus the discovery of nickel carbonyl led him into the nickel refining business with momentous consequences, both personal and national.

* Made by Mr. H. Broun-Morison for The Mond Nickel Co., Ltd.

Ludwig Mond was a man of wide interests in science, art and the humanities. He was a pioneer in industrial welfare. But it is as a chemist of genius that he is rightly remembered, for it was discoveries made in laboratories under his direction, and his application of these discoveries on an industrial scale, that have earned him a place in the history of chemistry.

New Giant Crushers at Nickel Mines

Five massive crushers have recently been installed by The International Nickel Co. of Canada, Ltd., at its Creighton and Frood-Stobie Mines in Northern Ontario, as part of the company's underground mining expansion programme. Each of these machines weighs 165 tons and crushes about 450 tons of ore an hour, reducing it to eight-inch chunks.

Ore dumped from haulage cars at the underground tipple rumbles down a chute leading to the crusher, which has a swing jaw weighing 16¾ tons. The speed of the ore feed to the crusher is regulated by seven huge chains with 110-pound links and a total weight of 13 tons. After passing through the crusher, the ore is ready for hoisting to the surface for further processing. The stations housing the many underground crushers in operation at International Nickel's mines are located from 500 to 5,000 ft. below the surface. Each station is lined with reinforced concrete and the back is supported by heavy steel beams.

Foundry Services, Ltd.

As further steps in their overseas development, Foundry Services, Ltd., are now operating two further associate companies, bringing the total number to five. Foundry Services (South Africa) Pty. Ltd., has been formed in association with Victor Kent (Transvaal) Pty. Ltd., and is under the managership of R. Cross, late of David Brown-Jackson of Manchester: headquarters are in Johannesburg. In Italy, Societa Italiana Catalizzatori has been formed in Milan. As well as a wide range of Foseco products, technical service facilities are available through both companies.

NEWS AND ANNOUNCEMENTS

Engineering Exhibition

The 19th Engineering, Marine and Welding Exhibition and the Chemical Plant Exhibition will be held at Olympia from Thursday, September 3rd, to Thursday, September 17th, inclusive. The Exhibition will remain open from 10 a.m. to 8 p.m. on all days except Sundays. The Exhibition was inaugurated in 1906, and has been held in alternate years ever since, except when interrupted by two World Wars. This year it will occupy more than a quarter of a million sq. ft., and will provide a mirror of progress in world engineering.

The Honorary President is Mr. D. D. Walker, and he is supported by nearly 300 patrons, including leading figures in public life and in the engineering industry. The sponsoring organisations are six in number, viz: The British Engineers Association, Inc.; The Society of Motor Manufacturers and Traders, Ltd. (Marine Section); British Electrical and Allied Manufacturers, Inc.; The Institute of Welding; The British Acetylene Association; and The British Chemical Plant Manufacturers Association.

There will be more than 500 exhibitors, and the exhibits will fall into five main groups—chemical plant, electrical, marine, mechanical and welding equipment. Covering practically the whole field of the engineering industry, they will range from a gas turbine, actually generating electricity for use in the Exhibition Halls, to gyro compasses; from single forgings of 50 tons to delicate control equipment; from the latest in welding equipment to a great diversity of chemical plant.

Birmingham Metallurgical Society

The Birmingham Metallurgical Society will be celebrating its Jubilee on Wednesday, October 21st, 1953, at the Grand Hotel, Birmingham, when the progress made during the last 50 years in various aspects of metallurgy will be reviewed by Dr. Maurice Cook (Non-Ferrous Industries), Dr. J. W. Jenkin (Ferrous Industries), Dr. T. Wright (Metallurgical Education), and Dr. N. P. Allen (Our Understanding of Metals). Between the morning session, which commences at 10 a.m., and the afternoon session, commencing at 3 p.m., there will be a Luncheon which the Lord Mayor is expected to attend.

Register of Specialist Indexers

To assist authors and publishers in their welcome efforts to achieve the highest possible standard of indexing in their published works, Aslib (formerly the Association of Special Libraries and Information Bureaux) is establishing a register of specialist indexers. The register will consist of persons who are available for part-time indexing only; a staff employment register is already maintained for indexers and other library staff seeking full-time employment of either a temporary or permanent nature.

Indexers will be enrolled in two categories: those who can produce evidence of indexing ability, and those who appear to possess the necessary qualifications but who have no published indexes to their credit. In both cases, evidence of special knowledge of one or more subjects will be required, so as to ensure competence in handling technical and other specialised material. No limitations to subject coverage are envisaged. All indexing work negotiated through the Aslib register will be subject to scrutiny and report as a means of ensuring that the register becomes and remains a recognised source of reliable subject indexers. It is hoped that, in time, the existence of the register will contribute materially to the consolidation of high standards of indexing in this country.

Requests for enrolment forms are invited from suitably qualified indexers, and information about the scope and operation of the register will be sent gladly to publishers and other potential users. Enquiries should be addressed to the Director, Aslib, 4, Palace Gate, London, W.8. Under the terms of the register, which is licensed annually by the L.C.C., no charge will be made to employers but a small enrolment fee and commission will be charged to those indexers who are accepted for enrolment, unless they are personal members of Aslib, when no charge will be made. Aslib will introduce suitable indexers to employers seeking its help, but the negotiation of indexing fees will be a matter for arrangement between the employer and the indexer direct.

Graduate Course in Industrial Metallurgy

The Graduate Course in Metallurgy at the University of Birmingham is part of a national scheme to maintain a supply of men fitted for technical positions of major responsibility in industry. It provides a year's training in industrial metallurgy at a post-graduate level for men who hold degrees in metallurgy, physics, chemistry or engineering and who are already engaged in, or proposing to enter, metallurgical industry.

In the 1953–54 course, which begins on October 5th, lectures and tutorial classes will be given on each of the thirty topics listed below and in the majority of cases topics will be treated in six to eight lectures. Students are invited to select about twenty of the topics for study during the session. In this way it is possible to cater to a great extent for individual needs and preferences.

List of Topics

Group A : — Technical control of industrial processes; metal economics; economic control of industrial processes; principles of substitution; principles of organisation within industry; andprinciples of management.

Group B : — Metallurgical thermodynamics; introduction to metal physics; theories of deformation; and phase transformations.

Group C : — Thermodynamics of melting and refining; steel melting; casting of ingots; solidification of metals; and heat transfer.

Group D : — Introduction to the theory of rolling; calculation of rolling loads and horsepower; deep drawing and cold pressing; and welding.

Group E : — Radiography and application of radioactive isotopes; instrumentation and non-destructive testing; modern optical and microscopical techniques; and selected topics in X-ray crystallography.

Group F : — Recent developments in materials; mechanical properties of castings and forgings; surface treatment of metals; and defects and failures in metallurgical materials.

Group G : — Business principles; mathematical statistics; and electrical plant engineering.

Practical work is carried out principally with the full-scale manufacturing plant in the new Aitchison Laboratories. The course includes studies in metallurgical works of problems arising in industrial production, and extensive use is made of the seminar system in which students present papers for discussion on selected topics in industrial metallurgy. On satisfactory completion of the course, students receive the Diploma in Post-Graduate Studies (Metallurgy).

The inclusive fee for the Graduate Course in Metallurgy is £71 1s. 0d. Forms of application may be obtained from the Registrar, The University, Edgbaston, Birmingham, 15.

Light Metals Congress Postponed

The " Montanistische Hochschule " of Leoben (Austria) intended to hold a Congress of Light Metals in the summer of 1954, but in view of the fact that an International Aluminium Congress is to take place in Paris in 1954—on the occasion of the centenary of technical production of aluminium by Sainte-Claire Deville—the Congress at Leoben will be postponed until the summer of 1955.

Students' Works Visits

Wild-Barfield Electric Furnaces, Ltd., are again extending, to senior students of technical colleges and like institutions, an invitation to visit the works at Watford during the coming winter season from October to May. The tours include visits to the Research and Development Departments as well as a tour of the production side of the works, and take place during any afternoon from Monday to Friday. Early application, giving alternative dates, is advised.

Personal News

Mr. J. R. Gordon, Vice-President and General Manager of Canadian Operations of the International Nickel Company of Canada, Ltd., has been elected a Director of the Company. He succeeds the late Mr. R. L. Beattie who had been Vice-President of the Company since 1942 and a Director since 1943.

Mr. D. Boxall has resigned his position at Southern Forge, Ltd., in order to take a post as Technical Liaison Officer with The British Non-Ferrous Metals Research Association.

Mr. P. Trier and Mr. G. Knott have been appointed Joint Managers of the Mullard Research Laboratories.

Mr. O. W. Humphreys and Mr. A. L. G. Lindley have been appointed to the Board of The General Electric Co., Ltd. Mr. Humphreys is Director of the Research Laboratories of the Company at Wembley, and Mr. Lindley is General Manager of the Fraser & Chalmers Engineering Works.

The Directors of Wickman, Ltd., announce that Mr. H. Eckersley, General Manager of the Wimet Division, and Mr. W. V. Hodgson, General Manager of the Machine Tool Division, have been appointed to the Board of the Company, whilst Mr. R. J. Dixon, Chief Engineer, Mr. T. W. Hayes, Export Sales Manager, and Mr. S. W. Perkins, Machine Tools Sales Manager, have been made special Directors.

Jenolite Technical Sales Service has been expanded by the appointment of a further Technical Sales Representative, Mr. R. E. Gray of 250, Cowdray Avenue, Colchester, Essex.

The Steel, Peech & Tozer Branch of The United Steel Cos., Ltd., announces that Mr. H. McWhinnie, J.P., retired from the position of General Sales Manager on June 30th, 1953, but is remaining with the Company for a period in order to advise on Sales Development. He will also continue to be the Company's Representative on certain Trade Associations and Committees. With effect from 1st July, 1953, the position of General Sales Manager at this Branch has been discontinued and all Departments responsible to the Commercial Director (Mr. W. T. Vizer-Harmer) are now co-ordinated through and supervised by, the Assistant Commercial Manager, Mr. J. Mackenzie-Mair.

Mr. E. D. E. Andrewes, a Director of Tube Investments Ltd., and until recently Managing Director of the company's export organisation, TI (Export) Ltd., has been appointed Joint Managing Director of Accles & Pollock Ltd., of Oldbury, a member of the TI group.

On Tuesday, 21st July, at the Ivy Restaurant, London, Mr. Fraser W. Bruce, Managing Director of Northern Aluminium Company Limited, presented aluminium watches to Mr. R. G. Hull, Manchester Sales Area Manager, Mr. E. Kitchen, Bristol Sales Office, and Mr. W. A. S. Nash, Chief Engineer, Rogerstone Works, in recognition of their 25 years' service to the Company.

Mr. P. J. Black, of Cambridge University, has been appointed to a Mr. and Mrs. John Straffe Donation Studentship to carry out research on the structural studies of intermetallic compounds at the Crystallographic Laboratory, Cavendish Laboratory, Cambridge.

Obituary

We regret to announce the deaths of the following :—

Mr. James J. Fraser, Managing Director of Honeywell-Brown, Ltd., who died at his home on Friday, July 17th, 1953, aged 51. Born at Grantown-on-Spey in Scotland, he graduated from Edinburgh, and spent a number of his early years in West Africa. In 1928 he joined the Minneapolis-Honeywell organisation in Canada, where he became Manager of the Montreal office. When, in 1936, a decision was taken to form the British Company of Honeywell-Brown, Ltd., Mr. Fraser was chosen for this work. As Managing Director since its inception, he has been directly responsible for its growth and development over the years.

Sir Johnstone Wright, a Director of British Insulated Callender's Cables, Ltd., since 1948, who died on Sunday, July 19th, 1953. Educated at Perth Academy and the Royal Technical College, Glasgow, Sir Johnstone gained wide experience of the electrical supply industry with various power companies and municipal undertakings before joining the Central Electricity Board in 1927. From 1933 to 1944 he was Chief Engineer; in 1944 he was promoted General Manager; and in 1947 he became chairman of the Board. Sir Johnstone retired from the C.E.B. the following year and became a Director of B.I.C.C., where his experience and great knowledge of the industry proved invaluable.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Automatic Control of Interior Lighting

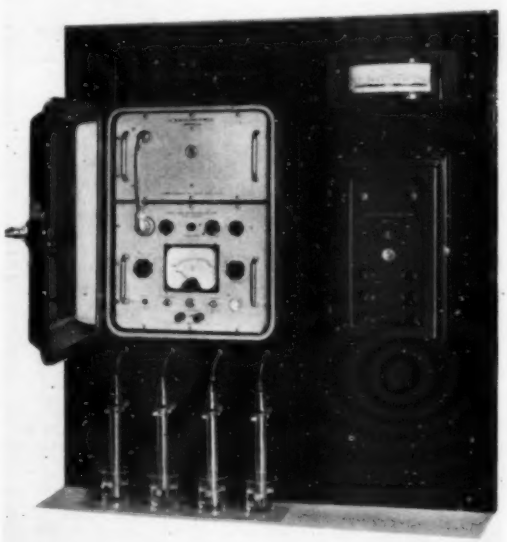
An interesting addition to the range of photo-electric equipment manufactured by Radiovisor Parent, Ltd., is the Mark XV automatic control for interior lighting. This unit, which operates from daylight intensity only, has been designed to give a finer degree of control than is obtainable with the Mark X unit which for many years has been in extensive use for street lighting.

One of the difficulties with the use of photo-electric equipment for interior lighting control is that the lighting may be switched on because the daylight intensity has been momentarily reduced by a passing cloud. To avoid this continual switching on and off for short periods, the Mark XV unit incorporates a time delay which prevents operation of the equipment until the changed light conditions have lasted for five minutes. If it is desired to use the unit without the delay, the latter can be cut out by means of a switch.

Radiovisor Parent, Ltd., 1, *Stanhope Street, London, N.W.*1.

The Multi-Electrode *p*H Indicator

THERE is often a need in the chemical industry to record the *p*H values at various stages in a manufacturing process. The cost of providing a number of individual *p*H recorders for this purpose may be prohibitive and in order to overcome the difficulty, Electronic Instruments, Ltd. have recently introduced a self-contained electrode switching unit, the purpose of which is to enable the readings of a number of *p*H electrode systems to be registered individually, on a single *p*H recorder located at some convenient point.



The electrode switching unit is designed to be used in conjunction with the Model 28 Industrial *p*H Meter made by this firm and this, in turn, may be connected to any of the conventional multi-point recorders which are widely used in the chemical industry. The multi-electrode unit may be operated manually or it may be arranged to be switched automatically in synchronism with the multi-point recorder, so that each electrode system in turn is connected to the *p*H meter for the length of time required for the recorder pen to make the appropriate trace. From one to six electrode systems may be connected to the switching unit and a separate control is provided to compensate individually for the asymmetry potential of each system. A visual indicator shows which electrode is in circuit at any given moment, and a simple over-riding manual control enables any particular electrode to be selected at will.

Electronic Instruments, Ltd., Red Lion Street, Richmond, Surrey.

Desk-Top Photo-Copying

With the introduction of the Duostat printer and processor, photo-copying has become a simple desk-top operation calling for little skill and no photographic knowledge. When the recommended Kodak Autopositive paper is used, the operation can be carried out under ordinary artificial light. The process is a clean, quick, semi-dry one, and no camera, dishes, running water, etc., are required.

After being exposed in contact with the document in the Duostat printer, the sheet of Autopositive paper is processed on the Duostat processor. It is placed face up on an absorbent porous block, and developer is applied by means of a sponge applicator. During development excess developer is absorbed by the porous block. The same operation is repeated using the stabilizer. Total processing time is about one minute. The print is then squeegeed to remove surface liquid, taken off the porous block and pressed between two sheets of Fotonic photographic paper. It is then dry and ready for handling.

Kodak, Ltd., Wealdstone, Harrow, Middlesex.

Universal Folders

A HIGH-LIFT clamping beam to accommodate right-angle forming blades, large-radius blades and mandrels, and a stepped-down bed to take small return bends are notable features of the new " Besco " Heavy Universal Folding Machines, which have been redesigned and introduced in five sizes by F. J. Edwards Ltd.

Designed to perform all edging, bending and folding operations in up to 14 gauge mild steel (16 gauge in the case of the two largest models), these machines will make both round and sharp bends. With an angle blade, channel and similar sections, mouldings and four-sided pans or trays can be formed from one piece of material, and with mandrels small trunks can be made. Hooks can be formed for side seams and the edges of sheets U-ed to take a wire.

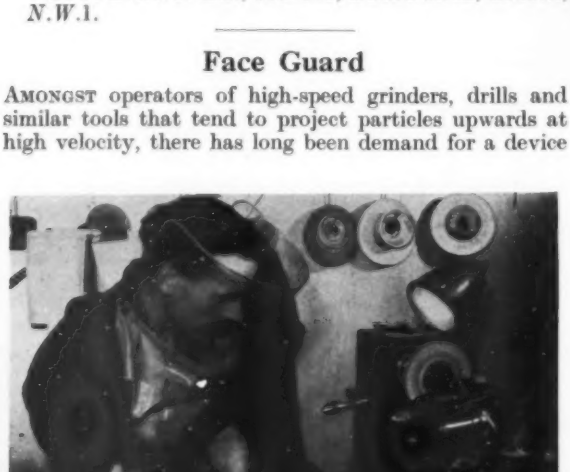
Constructed for floor mounting, the side frames, box-section legs and beams are of cast iron. The folding and clamping beams are also of stout box section and a centre supporting leg is fitted to the three larger models. The clamping beam is mounted on screws at each end with ball thrust bearings and operated by a handwheel through bevel gears, giving a 6 in. lift. The folding beam operates by a direct pull-up and is counterbalanced. It has 2 in. adjustment in the side arms for round and sharp bends, and an adjustable angle stop for repetition bending. There is an auxiliary blade for strengthening purposes, which can be removed for producing narrow return bends in lighter gauge metal. Here, too, the value of the stepping-down of the bed behind the clamping edge is apparent. An adjustable back gauge is fitted with fingers to suit narrow strips of metal fed from the front of the machine.

Standard equipment comprises one sharp edge blade and one round nose blade for small radii and U-bends. Special radius blades and right-angle forming blades for tray work are extras. The five models, by blade length and capacity, are the 49 in. × 14g., 61 in. × 14g., 74 in. × 14g., 98 in. × 16g., and 109 in. × 16g. The illustration shows the 74 in. × 14g. model.

F. J. Edwards Ltd., 359–361, *Euston Road*, *London*, *N.W.*1.

Face Guard

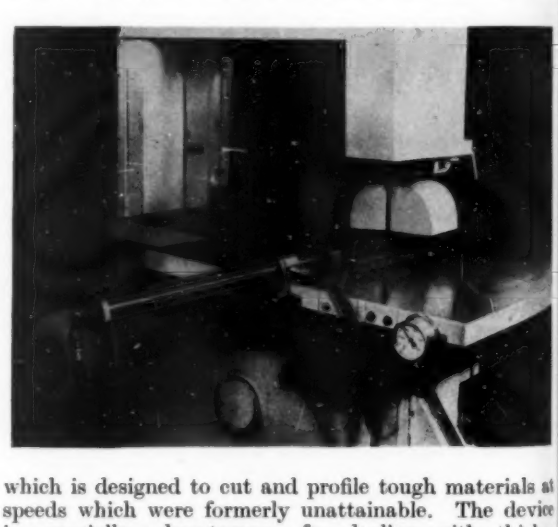
AMONGST operators of high-speed grinders, drills and similar tools that tend to project particles upwards at high velocity, there has long been demand for a device which would guard the face more effectively than conventional goggles or headband-suspended face shields. A solution to this problem, based on careful experiment and consultation with leading industrial users, is offered by the Protective Industrial Clothing Division of the R.F.D. Co. Ltd., who have produced the R.F.D. Shoulder-Braced Face-Guard. This is a completely new departure in facial protection, the shield being firmly supported by comfortable felt-lined shoulder braces. A lightweight chemical-proof or flame-proof fabric bib is attached to the lower edge of the shield to protect the neck and chest. The full-vision face shield, which can be supplied clear or tinted, is trimmed with aluminium and completely protects both front and sides of the head. The whole equipment can be adjusted or released in a moment, and while wearing it the operator has both hands completely free.



R.F.D. Co. Ltd. Catteshall Lane, *Godalming*, *Surrey*.

Power Feed Attachment for the "Metalclad" Fusion Cutter

A COMPACT power feed attachment for the "Metalclad" Fusion Cutter has been developed by George Cohen, Sons and Co. Ltd., the world distributors of this machine, which is designed to cut and profile tough materials at speeds which were formerly unattainable. The device is especially advantageous for dealing with thicker materials—say from ½ in. to 1 in.—and for making straight cuts, since it relieves the operator of all manual effort. In fact, the workpiece having been placed close to the cutting band, it is merely necessary to press a starter button. A small motor-driven pump actuates the unit which consists, in the main, of a double-acting hydraulic ram, with a stroke of 13 in. attached to the table of the machine. Embodied are a return flow relief-valve, by means of which the working pressure may be finely adjusted, and a control valve with forward, return and neutral positions. When the power feed is not required, the ram unit may be detached in a minute, or so, by the simple removal of two bolts. This leaves the table clear for profiling or hand feeding; but re-fitting only takes a couple of minutes.



George Cohen, Sons and Co. Ltd., *Wood Lane*, *London*, *W.*12.

CURRENT LITERATURE

Book Notices

THE BEHAVIOUR OF ALUMINIUM ALLOY RIVETED JOINTS

By Prof. A. J. Francis. 96 pp., numerous graphs and diagrams, paper covers. Research Report No. 15, published by The Aluminium Development Association, London, 1953. 7s. 6d.

THIS is a report on work carried out by the author at the University of Birmingham, sponsored and initiated by the Aluminium Development Association. It is concerned with theoretical and practical investigations into the action of double shear riveted joints in aluminium alloy under axial and under eccentric loading, in the elastic range and beyond : information was sought on the behaviour of joints with rivets of $\frac{1}{2}$ in. diameter and over. The increasing use of aluminium in structural work has made this information of growing importance, and its value is emphasised by the tendency hitherto of designers—lacking the full data—to apply to aluminium the standard practices for steel despite differences in the mechanical properties and riveting techniques of the two metals.

This work has led to a number of recommendations for the two main types of joint investigated, on the effects of rivet material and material of members ; of rivet pitch and d/t ratio ; of asymmetry of members and arrangement of rivets ; and other factors in the partition of load among rivets. Conclusions are drawn concerning the selection of rivet and member material in relation to joint efficiency. This is felt to be an extremely important contribution to the subject, and no less important in view of a surprising gap in the corresponding literature on iron and steel for which design methods are still based mainly on experience and *ad hoc* determinations of breaking strength.

It is believed that the present work, though not directly concerned with the behaviour of joints under fatigue, will provide helpful information for interpreting the results of repeated load tests.

PROCEEDINGS OF INTERNATIONAL SYMPOSIUM ON ABRASION AND WEAR

66 pp., numerous illustrations, paper backs. Published by The Rubber-Stichting, Oostsingel 178, Delft (Holland). Hfl. 6 (six Dutch florins).

To inaugurate their new premises, the directorate of the Rubber Stichting at Delft—the Dutch research organisation which, in collaboration with the British Rubber Producers' Research Association and the Institut Francais du Caoutchouc, seeks to promote the wider and more efficient use of rubber—organised a symposium on abrasion and wear towards the end of 1951. The proceedings of this symposium have now been published and are available from Delft.

Engineers have paid much more attention to rubber, and have studied more closely its peculiar physical and chemical properties, since the discovery and widespread adoption of methods of bonding rubber to metal, but their familiarity with it is still tinged with a certain degree of uncertainty, and much of the knowledge that chemists and physicists have now accumulated by painstaking investigation is by no means widely disseminated. Naturally, the emphasis is on those aspects of abrasion and wear which concern rubber in particular and non-metallics in general, but a few of the papers deal with factors of metallurgical interest, whilst others refer to general features of the problem. Professor Broeze, head of the Royal Dutch Shell Laboratory in Delft, where for many years the wear in internal combustion engines has been studied, presents a survey of those cases where the cause of wear appears to be totally or partially of a chemical nature including, as examples, the damage to bearings by substances produced by oxidation of lubricating oil, and the abrasion of cylinders and piston rings through the effect of acids condensing in cold engines. In another paper, Professor Blok, who has been carrying out research at the Royal Dutch Shell for many years, deals with wear as a general engineering problem, and with his own work concerning wear and lubrication of metal engine parts.

Other papers include " Friction and Surface Damage of Non-Metallic Solids," by Dr. F. P. Bowden ; " Morphological Aspects of Abrasion and Wear," by Dr. G. Salomon ; " Some Investigations of the Abrasion of Paints," by Dr. N. A. Brunt ; " Elementary Aspects of Rubber Abrasion," by Dr. A. Schallamach ; " Abrasion and Wear of Rubber," by J. M. Buist ; " Factors Influencing the Road Wear of Tyres," by R. D. Stiehler, M. N. Steel and J. Mandel ; " Survey of the International Symposium on Abrasion and Wear," by Dr. H. C. J. de Decker ; and " Methods of Testing Abrasion and Wear in the Netherlands," by P. Braber and G. Salomon.

Trade Publications

JOHN G. STEIN & Co., Ltd., Bonnybridge, Scotland, have issued a new publication dealing with high alumina refractories, that is, those refractories consisting essentially of alumina and silica whose content of alumina is higher than that of refractories made from fireclay alone. The improved properties obtained with these refractories are due to the presence of large amounts of mullite ($3Al_2O_3\ 2SiO_2$) and in some cases corundum (Al_2O_3). After dealing with the general properties of this group of refractories, the booklet gives the technical details of a range of bricks including Stein 50, Stein 63, Stein 70, Stein 73, Stein Sillimanite and Stein Mullite (the figures give the approximate alumina content). Under the severe conditions for which high alumina refractories are required, special refractory cements are necessary, and reference is made to Stein Sillimanite Cement and Stein High Alumina Cement (both heat setting) and two air setting cements (Maksiccar Fire Cement and Maksiccar II Refractory Cement). Two types of ramming materials, Stein Sillimanite Patch and Stein 73 Patch are also detailed.

A NEW publication entitled " Permanent Magnets " has recently been published by the Magnet Department of Mullard Ltd. This book has been prepared to meet the needs of engineers and designers who require an up-to-date and authoritive reference on the performance and characteristics of modern permanent magnets. A particularly interesting feature of the book is the inclusion of comparative charts and characteristics

relating to all permanent magnets commercially available at the present time. Reference is also made to the magnetic behaviour of the commercial irons and steels normally use in conjunction with permanent magnet alloys. The new book, which is attractively and informatively illustrated, contains sections on the manufacture, design and performance, characteristics and applications of Mullard Ticonal cast and sintered magnets, Magnadur ceramic magnets, and Reco cast magnets. There is in addition an interesting section dealing with magnetic symbols and terms. Copies may be obtained from Century House, Shaftesbury Avenue, London, W.C.2.

An interesting and informative pamphlet has recently been issued by British Electro Metallurgical Co., Ltd., Wincobank, Sheffield. It deals with the use of SMZ alloy as a ladle addition to cast iron. Essentially a balanced alloy containing 60–65% silicon, 5–7% manganese, 5–7% zirconium, and approximately 20% iron, SMZ exerts a particularly strong graphitising effect when used as a ladle addition in making cast iron. It is especially recommended for (a) producing a high-strength cast iron from a low-carbon, low-silicon iron; (b) producing an improved grey cast iron by means of a ladle addition; (c) reducing chilling of edges, corners, and thin sections of a casting without sacrificing mechanical properties in the heavier sections; (d) reducing wall sensitivity; and (e) bringing cast irons containing up to at least 2% chromium within the machinable range while maintaining or improving heat resistance, oxidation resistance, and mechanical properties. Graphs and supporting figures are given illustrating the effectiveness of SMZ for these purposes.

A revised edition of "Aluminium Alloy Scaffolding," an Aluminium Development Association leaflet first issued in March, 1948, has just appeared. Since 1948, B.S.1139 : 1951 "Metal Scaffolding" has been published and establishes the composition and minimum mechanical properties for tubes and fittings, these conforming respectively with the requirements (for the alloys mentioned) of B.S.1476 and 1472. This has enabled the leaflet to be slightly recast, giving extracts from the requirements of B.S. 1139, followed under a distinctive heading by recommendations on practice. The latter deal with spacing and loading, couplings, and practice for the straightening of tubes and flattening of tube ends.

A handsome brochure issued by N. C. Ashton, Ltd., St. Andrews Road, Huddersfield, features Narite, an alloy which is claimed to be the ideal material for dies for pressing sheet metal. Narite is a complex aluminium bronze with an aluminium content controlled to ± 0·20% and a Brinnell hardness of 360–400. The high degree of homogenity of the alloy, resulting from the method of manufacture, and the exceptionally close grain result in a material which is hard yet machinable and capable of taking a high polish, which emphasizes the characteristic "soapy" surface. The latter holds lubricants and reduces friction, thus helping to eliminate score marks on the pressings, particularly when such materials as stainless steel and the Nimonics are being handled. Other advantages claimed for Narite are that it work hardens at the surface of action; it will not rust; it can be cast to the die form; and, as it requires no heat treatment it cannot distort. Although Narite is machinable, such operations as turning, drilling, tapping and polishing are more readily carried out by the special techniques outlined in the brochure.

A small book called "Heat Treatment of Aluminium Alloys," issued in 1948, drew such favourable comment on its practical usefulness that Northern Aluminium Co., Ltd., have been encouraged to reprint it. Opportunity has been taken of making a complete revision in the light of five years' experience, and of adding many new photographs, but the aim and pattern of the book remain the same: offering in a simple manner practical advice on the solution treatment, precipitation treatment and annealing of aluminium, with just sufficient theory to give a better understanding of the principles underlying practice. No attempt has been made to produce a comprehensive treatise on this very complex subject. Description of the procedures employed and the equipment used in all the different forms of heat treatment is freely illustrated by photographs, and some ten pages of tables provide a ready guide to the recommended and specified treatments for the various Noral alloys.

Books Received

"Influence of the Wash from Bronze on the Weathering of Marble." By Daniel W. Kessler and Ross E. Anderson. National Bureau of Standards' Building Materials and Structures Report 137. 11 pp. Washington, 1953. U.S. Government Printing Office. 15 cents.

"Radiation Suppressing Coatings for Metals at Elevated Temperatures." By A. H. Sully, M.Sc., Ph.D., F.I.M., F.Inst.P., E.A. Brandes, B.Sc., A.R.C.S., F.I.M., and R. B. Waterhouse, B.A., A.I.M. (Special Report No. 1). 24 pp. Stoke Poges, 1953. Fulmer Research Institute. 15s. net.

"Plansee Proceedings, 1952." Edited by F. Benesovsky. Papers presented at the First Plansee Seminar, "De Re Metallica," held June 22–26, 1952, in Reutte/Tyrol. 316 pp. inc. numerous illustrations. Reutte/Tyrol, 1953. Metallwerk Plansee Ges. M.B.H.

"S.S. Ocean Vulcan Sea Trials—." The Forces Acting on the Ship at Sea." The Admiralty Ship Welding Committee Report No. R.8. By Authority of the Lords Commissioners of the Admiralty. 175 pp. inc. numerous illustrations and 44 tables. London, 1953. Her Majesty's Stationery Office. 35s. net.

"The Joining of Metals." (Lectures delivered at the Refresher Course, 1951.) 174 pp. inc. numerous illustrations. London, 1953. The Institution of Metallurgists. 14s.

"The Metallurgy of the Rarer Metals." (Lectures delivered at the Refresher Course, 1952.) 156 pp. inc. numerous illustrations. London, 1953. The Institution of Metallurgists. 15s. 6d.

"Statistical Year Book for 1952." Part I. United Kingdom Statistics. 114 pp. (94 tables). London, 1953. British Iron and Steel Federation. 7s. 6d.

"Properties of Metallic Surfaces." A Symposium organized by the Institute of Metals and held at the Royal Institution, London, on November 19th, 1952. Institute of Metals Monograph and Report Series, No. 13. 368 pp. inc. discussion and index. London, 1953. The Institute of Metals. 35s. or $5.50.

"Copper in Instrumentation." C.D.A. Publication No. 48. 152 pp. inc. 45 illustrations. Radlett, 1953. Copper Development Association. Copies of this book are obtainable free of charge on application to the Association.

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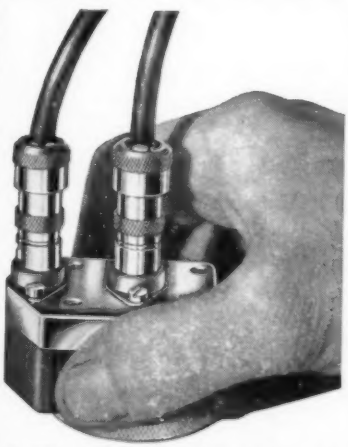

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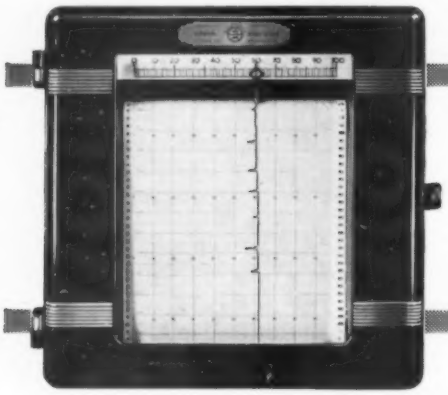

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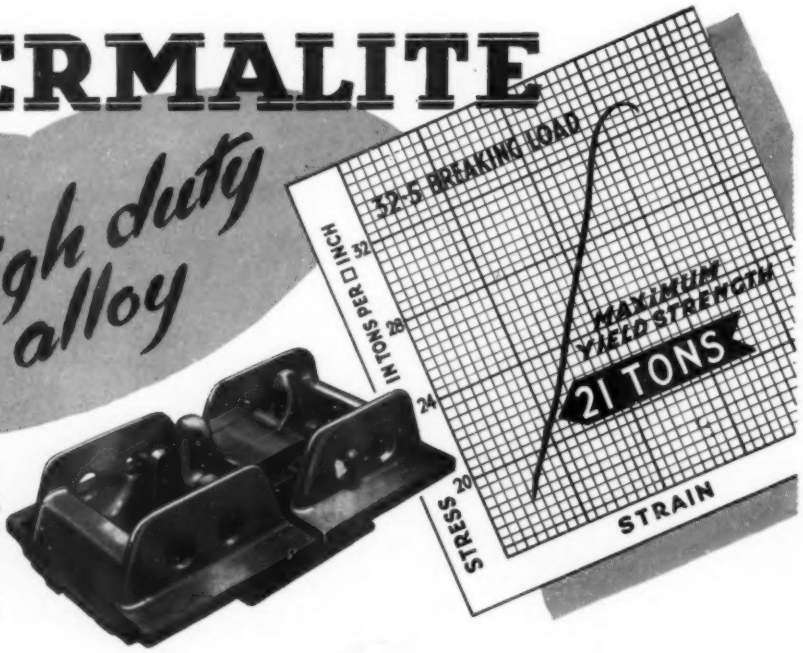

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LABORATORY METHODS
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INSTRUMENTS AND MATERIALS

AUGUST, 1953 Vol. XLVIII, No. 286

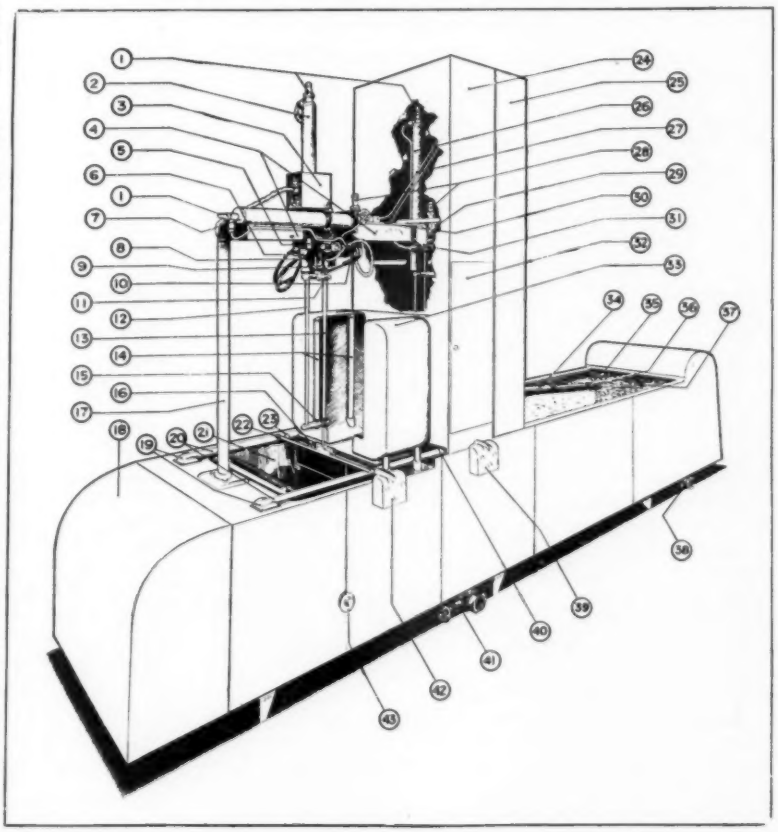
Automatic X-Ray Film Processing Unit

THE problem of developing and fixing large numbers of X-ray films has become increasingly important in recent years, and the continuing rise in costs of both labour and materials justifies the installation of special apparatus if this, in handling the films, gives uniform processing and reduces the number of darkroom technicians. To be capable of dealing with any films that require processing, however, such an apparatus must allow for considerable latitude in development time and the easy and early inspection of certain films.

The N.R.D. Automatic Film Processing Unit, marketed by Nucleonic and Radiological Developments, Ltd., is so designed that the input end of the unit is in the darkroom and the output end in the viewing room, the films leaving the darkroom and entering the viewing room while fixing. From this time on they are available for inspection. The tanks, made of specially treated steel, are assembled as one continuous unit, and films in processing move at a constant speed down the entire length of the apparatus. This is achieved by the use of two endless rubber belts which are located in shallow troughs at either side of the tanks. The films in their hangers are placed manually at the correct point in the developing tank and move at a speed of 2 in./min. The actual time of development will depend on the temperature of the developer, and the position of the film when it starts development can, therefore, be adjusted, the side of the tank being calibrated to indicate the correct starting position for various temperatures. The film in its hanger now has to be lifted from one tank to the next. The lifting and transporting mechanism at this point consists of two cylinders, a long vertical lifting cylinder, and a traversing gear to carry the film the requisite distance forward.

Electro-Pneumatic Operation

Although electrically controlled, the actual movement is achieved by the use of compressed air. The sequence of operations is as follows: each of the film hangers—which are, of course, moving forward on the belts—comes into contact in turn with a trigger which operates a micro-switch. Should the hanger be resting crookedly on the belts, a stop directly opposite the trigger will prevent further movement until the other end has come



(1) Adjustable needle valves on cylinders. (2) Vertical cylinder. (3) Mercury switch. (4) Mono-rail. (5) Micro-switch. (6) Stop operating micro-switch. (7) Horizontal cylinder. (8) Solenoid. (9) Four-way valve controlling horizontal cylinder. (10) Four-way valve controlling vertical cylinder. (11) Adjustable needle valve. (12) Vertical piston rod. (13) Vertical guide rod. (14) Water spray pipes. (15) Four-way valve operating stop (horizontal cylinder). (16) "T" hook. (17) Mono-rail supporting column. (18) Refrigerator unit. (19) Belt guide wheels. (20) Endless belts. (21) Developing bath. (22) Film hanger. (23) Film hanger stop. (24) Light trap casing. (25) Separating wall. (26) Pneumatic unit (fixer bath). (27) Air feed pipes to three-way valve (not shown). (28) Adjustable needle valves. (29) Horizontal cylinder unit No. 2. (30) Horizontal cylinder No. 1 piston rod. (31) Four-way valve actuating stop (vertical cylinder). (32) Inpection door in light trap casing. (33) Spray rinse unit. (34) Endless belts in washing bath. (35) Guide wheels leading to electric motor drive (not shown). (36) Film hanger stops. (37) Washing bath. (38) Washing water regulating valve. (39) Micro-switch (fixer to wash). (40) Fixing bath. (41) Fixing bath emptying valve. (42) Micro-switch (developer to fixer). (43) Thermostatic control.

into line, the hanger then being at right angles across the tank before lifting. An air valve now opens, compressed air enters the lower part of the main cylinder, and pressure is applied to the under-surface of a piston. This is connected by a piston rod to an inverted " T "-shaped hook which engages with its counterpart on the top of the film hanger. The upward lift is sufficient to allow a 17 in. × 14 in. hanger to clear the top of the partition in the tank. The rate of air flow is adjustable and is so set that this first operation takes about 5 seconds, allowance being made for the reasonable draining of the film. Air now enters the traverse cylinder and the frame moves slowly forward. During this movement, the automatic spray rinsing unit comes into play and the water drains into a drip-tank prior to the film being lowered into the fixing solution. The hanger is lowered into the fixing tank, and when its ends are again resting on the belts a slight continuation of the down stroke clears the " T " hook from the hanger, and the hook returns ready to lift the next film. The time of the complete cycle is adjustable by the control of the air flow for each movement. A simple light-trap coincides with the point where the tanks pass through the wall of the darkroom, and the film passes from fixer to final wash, by means of another electro-pneumatic lifting and lowering process. Half an hour is allowed for washing, and by this time the films have travelled the full length of the washing tanks. When no films are being processed, only the belts continue to operate, all other working parts of the apparatus being at rest.

For easy servicing the electro-pneumatic units are of the same design and control. Friction between the rubber drive belts and the ends of the film hangers is sufficient but not excessive, so that if, for example, films are not removed at the end of washing, the machine continues to operate normally and the films remain at the end of the tank.

Two Films a Minute

Since each lifting unit completes its cycle in about 25 seconds, one film can be placed in the developing tank every half minute. An even faster rate than this is possible, but is inadvisable since there is a risk of two hangers being transferred together. The above speed gives a reasonable spacing of 1 in. between films down the length of the tanks and avoids the risk of the films damaging each other. It takes about 20 seconds to attach a film to the appropriate hanger and this, with the placing of the film in developer, is the only manual operation. No special skill is required to operate the unit, and anyone can learn the necessary details in a few hours. One individual alone can handle the full working rate of two films per minute.

A special type of film hanger has been developed for this unit, the normal clips that grip the film being replaced by short spikes, turned with a slight recess behind their points. These, while holding the film quite securely in position, have the advantage of greatly reducing the risk of one hanger getting interlocked with its neighbour and of damage to the film emulsion.

Radiographic staff may at first miss the facility of improving bad exposures by varying the development time, but no amount of juggling with the development ever really turns a bad exposure into a good film, and experience has shown that realisation that the initial exposure must be correct seems, if anything, to improve the general standard of the work.

Operating Speed Adjustment

There is normally an interval of 12 minutes between the time when films are placed in the developer and the time when their quality can be checked in the daylight. It is quite simple to alter operating speed so that all films will be available for inspection after eight minutes. This depends only on using a slightly higher developer temperature than the normal 68°/69° F. (which without doubt gives the best results), a shorter fixing time, and an increased belt speed. This last variation is obtained by an interchange of gear wheels in the motor unit; if necessary, however, a motor working at a higher speed can be supplied instead of the standard type. The temperature is maintained by thermostatic control which can be set to the required figure. For tropical conditions — or elsewhere if there is difficulty in keeping the temperature down—the unit can be supplied with built-in refrigeration.

No mention has been made of the vital part played by accurate control of the quality of the developer. Without strict control of this factor the description " automatic " would be a misnomer. The unit is fitted with an automatic counter which shows the number of films processed. A very simple method has been devised whereby, using this figure as a basis, constant strength is maintained. When the unit is in full use, about fifteen minutes each evening suffices to check and restore the working strength and level. Briefly, the process consists of adding a bromide-free replenisher and discarding small volumes of the total solution to maintain chemical balance. The whole 20 gallons are never thrown out, as this regeneration formula maintains the developer at constant strength. If an added precaution is required, special test films can be used to provide a weekly check. Processed in the usual way they show a graduated film density which is compared with a standard film.

Fastest Strip Mill Drive Ordered

An important order for electrical equipment for what will be the fastest mill in Great Britain for rolling tinplate strip has just been placed with The British Thomson-Houston Co., Ltd., Rugby. This is for the new plant at Velindre, near Swansea, of The Steel Company of Wales Ltd. The electrical equipment will include six D.C. motors, totalling 18,850 h.p. and specially designed for the application, two 8,000-kW motor-generators, and control gear of the latest type. The equipment will be used for driving a five-stand tandem cold rolling mill. This is an extremely high production mill and at its top speed of 5,000 ft. per minute (nearly 60 miles an hour) can produce a coil of tinplate strip six miles long in six minutes. This is faster than the same Company's similar mill at Trostre for which also BTH supplied the electric drive. The Consulting Engineers for the electrical equipment are McLellan & Partners.

Armstrong Whitworth (Metal Industries) Ltd.

BECAUSE it was felt that the name Sir W. G. Armstrong Whitworth & Co. (Ironfounders), Ltd. was not sufficiently closely related to the activities and products of the company, it has been changed to Armstrong Whitworth (Metal Industries), Ltd.

Profiloscope for Wire Drawing Die Inspection

New B.I.S.R.A. Instrument for Rapid Quality Control

SOME idea of the enormous amount of wire produced each year by the 300 wire drawers in Great Britain can be gained from the fact that in 1951, in steel alone, almost 850,000 tons of wire were drawn, i.e. about 5% of the total steel output. Until very recently, all this wire was drawn through wire drawing dies which could only be checked empirically to see whether they were the best shape internally.

The Wire Drawing Section of the British Iron and Steel Research Association has for some time been concerned with the development of an instrument to measure and inspect internal tapers of dies, and a few years ago the B.I.S.R.A. Profilometer was designed for use as a highly accurate research tool. Since then further work has been done in order to produce a cheap and simple instrument for use in the die shop.

The modern wire drawing die is made of tungsten carbide and shaped internally rather like a trumpet, but opening out slightly on the narrower side. The die must be correctly shaped in order to reduce die load and give good lubrication and long life; on these factors depends the quality of the drawn wire.

Optical Method

It seems logical to suppose that the best way of showing up scoring, which runs along the die, and ringing, which runs around the die, is by an optical method, and a few years ago workers in the U.S.A. and Germany showed that a parallel beam of light shining through a die could be used to measure the die angle and to estimate the degree of wear. The B.I.S.R.A. Profiloscope is an improvement on this method, which removes the need for a complicated optical system.

The instrument is based on a very simple principle in which a narrowly divergent light beam passes through the die, placed on a tilting table, on to a screen placed below. When the die is horizontal, a small bright circle of light is seen, outside which is a dark band, outside which again is a narrow band of light, all these being concentric one with another. The innermost circle is due to direct illumination through the die hole and the outer to internal reflection from the tapered region of the die. Should there be any change in taper, they will immediately become evident as more concentric light circles, one for each change in taper, while a gradual change in taper causes a wider band of light. Any scoring will show as light radial lines radiating from the centre circle and the effect may be intensified by tilting the die. Inspection of the die interior is therefore very simple.

Measurement of Die Angle

The Profiloscope may also be used to measure the die angle by tilting the die, whereupon the outermost circle of light distorts to a heart-shaped image; by sufficient tilting, the cusp at the top of the heart may be made to touch the innermost circle. In this position the direct ray through the die and the outermost reflected ray coincide on the screen. By tilting the die in the other direction a similar situation will be seen, but on the other side. The total angle of tilt of the platform 2ϵ may then be related to the die angle 2α by means of the relation:

$$2\alpha = 2\epsilon + \frac{a + d}{l} \text{(in radians)}$$

where a and l are instrument constants and d is the die diameter. It follows that before α can be found, the die diameter must be known. In practice, since a and d are small in comparison with l, no high degree of precision is required in the value of d.

For example, in a given instrument, typical values of a and l are $\frac{3}{32}$ in. and 8 in. respectively. Suppose a given die gives a value of 14° for 2ϵ and d is taken as 0·4 in., 2α then becomes 17·5°. Had an error been made, and the diameter of die been assumed to be 0·5, 2α would have been 18·2°. It follows then that the die diameter need only be known roughly. In practice, of course, d will be known quite accurately as it is equal to the diameter of the drawn wire.

The mathematical theory behind the Profiloscope, while not difficult, is somewhat complex, and in arriving at the equation quoted above, some assumptions have been made. Taking the most unfavourable conditions likely to be met with, however, the maximum error in

The Profiloscope.

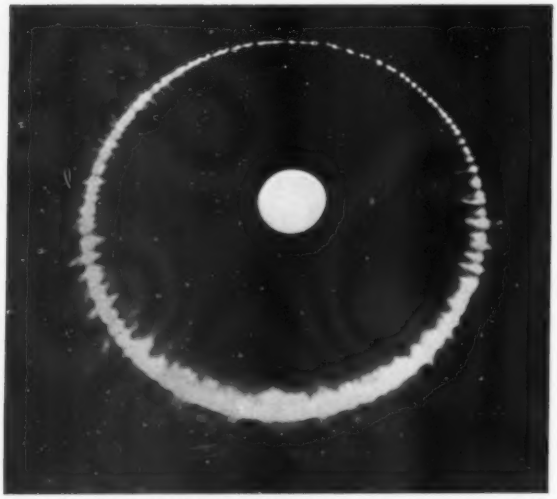


Image of die in horizontal position; shows taper partially removed and scoring beginning.

the measured value of the die angle, due to the assumptions made, is no more than 10 minutes of arc, and this is well within the designed accuracy of the instrument, which is $\pm \frac{1}{2}°$.

A further feature of interest is the ease with which the Profiloscope can be used for exceptionally rapid quality control of die profiles. Work trials have indicated that between 5 and 10% machine working time is lost by replacement of worn tungsten carbide dies. In one works investigated, this was estimated to cause a loss of output of 1,000 to 2,000 tons per year, worth some £35,000 to £40,000. Quality control by means of a robust and simple instrument such as the Profiloscope will enable wire drawing works to plan batch replacements economically, reducing this expenditure considerably.

All things considered, the Profiloscope may be presented as an instrument of limited accuracy, cheap and simple to use, giving die angles to $\pm \frac{1}{2}°$, and a very good picture of die wear.

British Standards Institution Moves

The British Standards Institution is now in full operation at its new premises: No. 2, Park Street, W.1. (Tel.: MAYfair 9000). As already announced, the new building will contribute to more efficient working by concentrating the B.S.I.'s scattered departments under one roof. It will also provide increased and more convenient accommodation for Committee meetings.

Copper Supply

British Copper Refiners Ltd., of Prescot, Lancashire, the largest producers of refined copper in the United Kingdom, announce that following the cessation on 5th August of Government control—imposed as a war-time emergency measure—they are now able to supply customers direct with wire bars, billets, cakes, ingots, and ingot bars in high conductivity copper and deoxidised arsenical copper to appropriate B.S. Specifications.

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